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A FORECASTING TECHNIQUE FOR OPERATIONAL RELIABILITY (MTBF) AND MAINTENANCE (MMH/FH).

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DEPUTY FOR A-10
DIRECTORATE OF SYSTEMS ENGINEERING
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Traditionally, there has been little or no correlation between contractual R&M parameters and operational values. The differences between these values vary from one weapon system to another. The differences are mostly explainable, after the fact. However, little, if any, effort has been expended in an attempt to develop a method of forecasting operational R&M parameters. This report provides a method that can presently be used to forecast operational MTBF and MMH/FH parameters.

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FOREWORD

This report was prepared by the A-10 System Program Office, Directorate of Systems Engineering, Analysis and Integration Division, Wright-Patterson AFB, Ohio.

The report is a retrospect study of the development and validation of specific R&M forecasting techniques for the A-10A Close Air Support Aircraft. The report covers the time period from December 1975 through December 1976. The reliability sections of the report were developed by Mr. William E. Romans. Maintenance sections were developed by Captain William C. Widenhouse. Principal contributors to this study effort were Mr. T. Lynch, Lt Colonel D. Tetmeyer, Major R. Sweginnis, Major G. Hopkins, Major W. Rider, 2nd Lt R. Armstrong and Mr. C. Vitelli. Special recognition is given to Mrs. Bessie Shriner, Ms. Rae Davis and Miss Sandy Lee for their patience and understanding in the compilation and production of this report.

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SUMMARY

In recent years more and more emphasis has been placed on the correlation between contractual Reliability (MTBF) and Maintainability (MMH/FH) requirements and what is eventually witnessed in the field environment. Many studies have been undertaken, after the fact, to quantify and explain the differences between the two values. This report is an attempt to quantify, ahead of time, the operational R&M parameters for the A-10 aircraft. The methodology used, if proven accurate, can be used for other major weapons systems developments. This report shall contain the methodology used and the results of the initial study. Forecasts of MTBF and MMH/FH for a mature A-10 aircraft will be presented along with initial site activation values.

SECTION I

GENERAL INTRODUCTION

The objective of this report is to provide a methodology for forecasting operational Reliability and Maintainability (R&M) parameters for complex weapons in the acquisition process. Traditionally, there has been little or no correlation between contractual R&M parameters (MTBF & MMH/FH) and operational values. The differences between these values vary from one weapon system to another and also vary widely from subsystem to subsystem. The differences are mostly explainable, after the fact. However, little, if any, effort has been expended in an attempt to develop a method of forecasting operational R&M parameters.

One of the main differences between contractual and operational R&M values is that they are used for entirely separate and distinctly different purposes. Contractual MTBF and MMH/FH are used to evaluate the basic design characteristics of the equipment. Consequently, failures caused by maintenance error, mishandling, and the like are not generally counted as "relevant" to the design of the equipment. This is not to say that failures of this type are not significant. Specific failures resulting directly from an error of the maintenance technicians may be directly related to the basic design of the equipment. These types of failures should be evaluated in detail and corrective action proposed and implemented, where possible. In addition, failures of expendable items (e.g., light bulbs, tires, minor structural (non-stress carrying) items) are not counted as "relevant" failures against the contract unless the particular failures adversely affect the mission of the aircraft. Contractual maintenance manhours (sometimes referred to as chargeable) (MMH) are used specifically to evaluate the maintainability characteristics of the design. Administrative overhead, supervisory personnel and minimum crew sizes are rarely included in these values from a contractual standpoint. The objective is to measure/observe how many "direct" manhours are accumulated against the equipment as a result of the basic design philosophy. Consequently, manhours expended due to maintenance error, FOD and test instrumentation problems are not normally "chargeable" manhours.

On the other hand, the operational definition of failure commonly used in the Air Force counts each of the above exclusions as "failure occurrences" and rightfully so. The main purpose of these values is for both measurement of frequency of maintenance and for other logistic purposes. Regardless of the reason for failure, the item that has failed must be repaired and/or replaced. To accomplish this task spare parts must be allocated based on the actual consumption data. Similarly, the manhours reported through the normal AF system contain supervisor manhours, administrative manhours and on occasion some on-the-job training manhours. Therefore, it is easily understood why there exists a wide disparity in the values observed in the operational environments when compared with contractual values.

AFSC has been in the past, primarily interested in the basic design of the equipment under development and only secondarily involved with the logistic aspects of R&M. Consequently, contractual definitions of R&M have been developed to evaluate new weapons systems. However, increasing support costs have forced the developer to look more closely at the logistic aspects during the acquisition and development phases of a program. This report is one by-product of this added emphasis and will hopefully provide a method that can be used by future acquisition organizations to forecast/predict operational R&M values.

SECTION II

DEVELOPMENT OF OPERATIONAL RELIABILITY (MTBF) AND MAINTENANCE (MMH/FH) FORECAST METHODOLOGY

PART I - OPERATIONAL HARDWARE RELIABILITY (MTBF)

1. Introduction

Traditionally, the MTBF values observed in an operational environment are considerably lower than those observed throughout a contractual reliability (MTBF) verification program. Reasons for these differences vary from contract to contract and cannot be defined, before the fact, by a single "K" factor as has been attempted in other published papers/reports. The purpose of this part of the report is to develop a method by which any major weapon system acquisition organization, with equivalent preliminary information, can establish operational MTBF values prior to initial activiation.

The definition of failure used throughout this part of the report is consistent with the definition provided in AFLCM 6615 (C8). This definition was developed by the joint AFLC/AFSC Panel 34 "Single Thread Data System" and became effective in the AFLC D056 (Product Performance) RCS LOG-MMO (AR) 7170 (formerly LOGK261) summaries dated subsequent to 1 January 1972. Since this definition for failure is standard throughout many of the Air Force Commands, it was felt that pursuing a forecast methodology with this baseline definition was the only meaningful approach to be taken.

It is well documented that there are many peculiarities within the D056 data system. The methodology presented in the following paragraphs assumed that whatever inconsistencies presently exist within the system will remain relatively constant from one program to another. For example, it is assumed that keypunch error rates remain essentially constant from one weapons system to another. This is a key assumption throughout the entire mature forecasting methodology. Significant observed differences from those normally encountered (e.g., higher keypunch error rate) will affect the validity of the resultant forecast values.

The following paragraphs contain the detailed rationale used to forecast the A-10 air vehicle operation Mean Time Between Failure (MTBF). Paragraph 2 describes the method used to forecast a mature MTBF value. Maturity, for the A-10 is defined as the accumulation of approximately 71,000 fleet flying hours. This also relates to a calendar date of approximately 18 months after IOC (Initial Operating Capability) (this date is subject to change dependent upon utilization rates). Paragraph 3 describes the method used to forecast the MTBF which could be expected upon initial site activiation.

2. Mature MTBF Forecasting Methodology

The basic concept used in forecasting the mature MTBF for components, subsystems and eventually the air vehicle was comparability. An independent study was performed early in the design phase of the A-10 program. The purpose of that effort was to provide the manpower and planning people with early information on the amount of people that would be required to maintain and support the A-10 aircraft in the operational environment. These manpower specialists recognized the need for a frequency of repair index which they could use to assist them in establishing maintenance manpower requirements. This comparability study was the primary tool used to derive this index. The study was performed by ASD engineering specialists (e.g., Landing Gear, Environmental, Avionics, etc.). The study compared the proposed A-10 designs with existing Air Force inventoried systems. Complexity factors were developed which provided an index to measure "how comparable" the proposed A-10 design would be. These factors were updated following the A-10 Critical Design Review (CDR) in the MarchJune 1974 time frame to assure that new design developments were considered. These complexity factors were developed at the 3-digit Work Unit Code (WUC) level (e.g., HUD, Fuel Quantity Indicating System, Hydraulic Subsystem, etc.).

The A-10 forecasts were developed by applying these complexity factors against actual data on the respective comparable subsystems. For example, the A-10 Emergency Landing Gear and Landing Gear Control subsystems were compared to the A-7D equivalent subsystems. The resultant complexity factor was .9. This means that the A-10 design was 90% as complex as the A-7D subsystem. Actual failure data for this A-7D subsystem showed an 89 hour operational MTBF. Multiplying the actual value by the complexity factor resulted in the A-10 forecast.

Component forecasts were combined to developed subsystem forecasts. Subsystem forecasts were then used to develop a total air vehicle forecast. Tables 1 through 23 provide the details used in the development of most of the two-digit level WUC subsystem forecasts.

There did exist several subsystems for which the comparability study and resultant data was not directly relatable to the A-10 work unit code manual. That is, the comparability study only addressed the total system instead of the subsystems. It therefore became necessary to develop a method to allocate these system level MTBF values to the subsystem level. The only additional A-10 data that could be utilized for the purpose was the original failure rate predictions made by the prime contractor. Although these contractor generated failure rate predictions have been notoriously incorrect from the standpoint of the actual quantitative number that is predicted, the breakout of which equipments contribute most to the overall failure rates of subsystems have been reasonably accurate. Consequently, the following method was used to forecast mature operational MTBF values for those subsystems where comparability could not be used below the system (two digit WUC) level.

The contractor reliability math model was restructured to more closely resemble the present WUC manual breakout of systems.

The contractor failure rates were determined for those equipments contained within the two-digit WUC systems.

The individual component failure rates were then summed at the three-digit WUC level to determine the percentage contribution each of these subsystems had to the total system.

The comparable major subsystem (2-digit level WUC) failure rate was then allocated to each of the three digit minor subsystems based on the percentages developed in c. above.

These allocated failure rates were then converted to become the minor subsystem (three-digit WUC) MTBF forecasts. Tables 24 through 28 indicate which major subsystems were subjected to this allocation of forecasts.

3. Initial MTBF Forecast Methodology

When a weapon system is initially deployed into the operational environment there are normally many limiting factors that prevent the equipment from achieving its mature reliability goals. These limitations include, but are not limited to, such things as lack of sufficient technical data, lack of support equipment, unqualified hardware and insufficient operating time on equipments during the developmental test portion of the program to uncover design deficiencies. The combination of all these factors may account for a significantly different MTBF value (usually lower) than anticipated for a mature aircraft.

The first four production A-10 aircraft were delivered to the Tactical Air Command (TAC) in March 1976. Since the number of available aircraft and hence flying hours would be limited for the first several months the initial forecast point was chosen as the April through June

1976 time frame. Additional aircraft would be delivered in those months and the anticipated flying hours was approximately 400-450 hours. Additionally, because of the time lag between the collection and processing of failure data to the receipt and detailed analysis of the data, it was necessary to pick June 1976 as an end point in order to fulfill a report requirement to the Office of the Secretary of Defense (OSD) for future fiscal year funding. The report to OSD was due on 1 Sep 1976.

Since this study effort was performed while developmental flight testing was underway, actual A-10 failure data was used as the baseline for forecasting this initial value of MTBF. Nine months worth of actual A-10 experience of the AFFTC at Edwards AFB (Apr thru Dec 75) was analyzed in detail to determine the types of operational failures that were present. The entire aircraft was evaluated subsystem by subsystem and problem areas identified. It should be noted that over 85% of the problem areas by the operational MTBF definition were also considered problem areas from a contractual standpoint. Consequently, failure analyses had already been performed and, in many cases, corrective actions incorporated into the test aircraft. Because of this, the effectiveness of many of these corrective actions had been proven.

The initial forecast methodology was to take the actual MTBF's observed during this nine month test period and adjust those values based upon those corrective actions which had proven effective. This was strictly a subjective judgement on the part of the authors based upon their knowledge of the aircraft and the problems encountered. Great caution was exercised when evaluating those failures which had corrective action incorporated. Sufficient operating time was required on each fix prior to forecasting reliability improvement. This was a very conservative approach. Details of this method were not included in this report since this particular method is entirely dependent upon the weapons system. In addition, an initial forecast may be required prior to the availability of any operational failure data of the weapons system desired. The primary objective of this paragraph was to briefly describe this particular method which in turn may precipitate readers to develop more representative methodologies that may be used without the prerequisite of actual operational data.

4. Results

Table 29 is a summary of the forecasted MTBF's for both the initial time frame (Apr--Jun 76) and the mature time frame (Jul 79). The question arises as to how well these results compare with aircraft already in the Air Force inventory. Table 30 was developed to compare the mature A-10 MTBF forecast with actual MTBF's of other TAC maintained aircraft. As can be seen from the table the A-10 MTBF falls between the A-7D and A-37. This should be expected since the A-10 is, generally speaking, more complex than the A-37 and less complex than the A-7D. It is felt that this comparison partially validates the method used in forecasting the A-10 operational MTBF values.

TABLE 1

WUC 11XXX - AIRFRAME

A-10 WUC	COMPARABLE SYSTEM	COMPARABLE ACTUAL	COMPLEXITY FACTOR	MTBF FORECAST	FAILURE RATE
11A	A-7D	45	.95	47	.02128
11B	A-7D	88	.75	117	.00855
11C	A-7D	62	.83	75	.01333
11D	A-7D	67	.75	89	.01124
11E	A-7D	165	.75	220	.00455
11F	A-7D			134	.00746
11XXX - MATURE FORECAST-15 HRS MTBF					.06641

TABLE 2

WUC 12XXX - COCKPIT & FUSELAGE

A-10 UNC	COMPARABLE SYSTEM	COMPARABLE ACTUAL	COMPLEXITY FACTOR	MTBF FORECAST	FAILURE RATE
12A	N/A	-	-	-	-
12B	N/A	-	-	200	.00500
12G	A-7D	147	1.0	147	.00680
12K	A-7D	231	.90	256	.00391
12XXX - MATURE FORECAST-64 HRS MTBF					.01571

TABLE 3

__13XXX__ - __LANDING GEAR__

A-10 UNC	COMPARABLE SUBSYSTEM	COMPARABLE ACTUAL	COMPLEXITY FACTOR	MTBF FORECAST	FAILURE RATE
13A	A-7D (MECH)	179	.75	239	.00418
	A-7D (HYD)	1546	1.1	1405	.00071
	F-105 (WH & TIRES)	37	1.0	37	.02702
13B	A-7D (MECH)	678	.75	904	.00111
	A-7D (HYD)	2249	1.1	2045	.00049
	F-105 (WH & TIRES)	119	1.0	119	.00840
13C	F-4E	2075	1.0	2075	.00048
13D	A-7D	89	1.0	89	.01124
13E	A-7D	353	.9	392	.00255
13G	A-7D	1180	1.0	1180	.00085
13K	A-7D	1500	1.0	1150	.00087
	13XXX - MATURE FORECAST-17 HRS MTBF				.05790

TABLE 4

WUC 14XXX - FLIGHT CONTROLS

A-10 UNC	COMPARABLE SYSTEM	COMPARABLE ACTUAL	COMPLEXITY FACTOR	MTBF FORECAST	FAILURE RATE
14A	A-7D	1833	1.0	1833	.00055
14C	A-7D	56	1.0	56	.01785
14E	A-7D	135	.8	169	.00592
14G	A-7D	760	.8	950	.00105
14K	A-7D	62	.9	69	.01449
14L	A-7D	62	2.0	31	.03226
14N	T-37	435	2.0	218	.00459
14XXX - MATURE FORECAST-13HRS MTBF					.07671

TABLE 5

WUC 23XXX - PROPULSION

A-10 UNC	COMPARABLE SYSTEM	COMPARABLE ACTUAL	COMPLEXITY FACTOR	MTBF FORECAST	FAILURE RATE
23A-D	S-3A	38.5	1.0	38.5	.02597
23G	A-7D	42	1.9	22	.04545
23J	F-111A			225	.00444
23K	F-111A			146	.00685
	23XXX - MATURE FORECAST-12 HRS MTBF				.08271

TABLE 6

WUC 24XXX - AUXILIARY POWER

A-10 UNC	COMPARABLE SYSTEM	COMPARABLE ACTUAL	COMPLEXITY FACTOR	MTBF FORECAST	FAILURE RATE
24A	HH-53	29	.33	87	.01149
24C	A-7D	42	1.0	42	.02381
24E	HH-53	INCLUDED IN 24A			-
24G	HH-53	INCLUDED IN 24A			-
24XXX - MATURE FORECAST-28 HRS MTBF *					.003530

* It was assumed that there will be one APU operating hour for every flying hour.

TABLE 7

WUC 44XXX - LIGHTING SYSTEM

A-10 UNC	COMPARABLE SUBSYSTEM	COMPARABLE ACTUAL	COMPLEXITY FACTOR	MTBF FORECAST	FAILURE RATE
44A	-	-	-	573	.00175
44B	A-7D	105	1.0	105	.00952
44C-D	F-4E	64	1.0	64	.01563
	44XXX - MATURE FORECAST-37				.02690

TABLE 8

WUC 45XXX - HYDRAULICS

A-10 UNC	COMPARABLE SUBSYSTEM	COMPARABLE ACTUAL	COMPLEXITY FACTOR	MTBF FORECAST	FAILURE RATE
45A	A-7D	82	.75	108	.00952
45B	A-7D	82	.75	108	.00952
45D	*NCS	-	0	200	.00500

45XXX - MATURE FORECAST - 432 HRS MTBF

* NCS - No Comparable System

TABLE 9

47XXX - OXYGEN SYSTEM

A-10 UNC	COMPARABLE SUBSYSTEM	COMPARABLE ACTUAL	COMPLEXITY FACTOR	MTBF FORECAST	FAILURE RATE
47A	A-7D	91	1.0	91	.01099

47XXX - MATURE FORECAST - 91 HRS MTBF

TABLE 10

WUC 49XXX - MISCELLANEOUS UTILITIES

A-10 UNC	COMPARABLE SUBSYSTEM	COMPARABLE ACTUAL	COMPLEXITY FACTOR	MTBF FORECAST	FAILURE RATE
49A	F-105	1630	1.0	1630	.00061
49B	F-105	165	1.0	165	.00606
	49XXX - MATURE FORECAST-150 HRS MTBF				.00667

TABLE 11

52XXX - AUTO PILOT (SAS)

A-10 UNC	COMPARABLE SUBSYSTEM	COMPARABLE ACTUAL	COMPARABLE FACTOR	MTBF FORECAST	FAILURE RATE
52A	F-5E	629	6.0	105	.00952

52XXX - MATURE FORECAST - 105 HRS MTBF

TABLE 12

55XXX - MALFUNCTION ANALYSIS RECORDER

A-10 UNC	COMPARABLE SUBSYSTEM	COMPARABLE ACTUAL	COMPLEXITY FACTOR	MTBF FORECAST	FAILURE RATE
55A	F-11A	5C3	1.0	503	.00199
55B	F-4E	1788	1.0	1788	.00056

55XXX - MATURE FORECAST - 393 HRS MTBF

TABLE 13

62XXX - VHF COMMUNICATIONS

A-10 UNC	COMPARABLE SUBSYSTEM	COMPARABLE ACTUAL	COMPLEXITY FACTOR	MTBF FORECAST	FAILURE RATE
62A	A-7D	95	1.0	95	.01053
62B	C-5A	168	1.0	168	.00595

62XXX - MATURE FORECAST - 61 HRS MTBF

TABLE 14

63XXX - UHF COMMUNICATIONS

A-10 UNC	COMPARABLE SUBSYSTEM	COMPARABLE ACTUAL	COMPLEXITY FACTOR	MTBF FORECAST	FAILURE RATE
63A	F-5E	54	1.0	54	.01852

63XXX - MATURE FORECAST - 54 HRS MTBF

TABLE 15

64XXX - INTERPHONE

A-10 UNC	COMPARABLE SUBSYSTEM	COMPARABLE ACTUAL	COMPLEXITY FACTOR	MTBF FORECAST	FAILURE RATE
64A	A-37	147	1.0	147	.00680

64XXX - MATURE FORECAST - 147 HRS MTBF

TABLE 16

65XXX - IFF/SIF

A-10 UNC	COMPARABLE SUBSYSTEM	COMPARABLE ACTUAL	COMPLEXITY FACTOR	MTBF FORECAST	FAILURE RATE
65A	F-15	154	1.0	154	.00649

65XXX - MATURE FORECAST - 154 HRS MTBF

TABLE 17

71XXX - RADIO NAVIGATION (TACAN)

A-10 UNC	COMPARABLE SUBSYSTEM	COMPARABLE ACTUAL	COMPLEXITY FACTOR	MTBF FORECAST	FAILURE RATE
71A	FB-111	122	1.0	122	.00820
71J	A-7D	1269	1.0	1269	.00079

71XXX - MATURE FORECAST - 111 HRS MTBF

TABLE 18

74XXX - FIRE CONTROL

A-10 UNC	COMPARABLE SUBSYSTEM	COMPARABLE ACTUAL	COMPLEXITY FACTOR	MTBF FORECAST	FAILURE RATE
74A	A-7D	38	.5	75	.01333
74C	NCS	-	-	50	.02000
74E	NCS	-	-	50	.02000

74XXX - MATURE FORECAST - 188 HRS MTBF

TABLE 19

75XXX - WEAPON DELIVERY

A-10 UNC	COMPARABLE SUBSYSTEM	COMPARABLE ACTUAL	COMPLEXITY FACTOR	MTBF FORECAST	FAILURE RATE
75A	NCS	-	-	119	.00840
75B	NCS	-	-	50	.02000
75C-H	A-7D	64	1.3	49	.02041
					.04881

75XXX - MATURE FORECAST - 20 HRS MTBF

TABLE 20

76XXX - ECM

A-10 UNC	COMPARABLE SUBSYSTEM	COMPARABLE ACTUAL	COMPLEXITY FACTOR	MTBF FORECAST	FAILURE RATE
76A	F-4E	206	1.0	206	.00485
76C	F-4E	1028	1.0	1028	.00097

76XXX - MATURE FORECAST - 172 HRS MTBF

TABLE 21

91XXX - EMERGENCY EQUIPMENT

A-10 UNC	COMPARABLE SUBSYSTEM	COMPARABLE ACTUAL	COMPLEXITY FACTOR	MTBF FORECAST	FAILURE RATE
91A	A-7D	226	1.0	226	.00442

91XXX - MATURE FORECAST - 226 HRS MTBF

TABLE 22

96XXX - PERSONNEL & MISC. EQUIPMENT

A-10 UNC	COMPARABLE SUBSYSTEM	COMPARABLE ACTUAL	COMPLEXITY FACTOR	MTBF FORECAST	FAILURE RATE
96A	F-105	9896	1.0	9896	.00101

96XXX - MATURE FORECAST - 9896 HRS MTBF

TABLE 23

97XXX - EXPLOSIVE DEVICES & COMP

A-10 UNC	COMPARABLE SUBSYSTEM	COMPARABLE ACTUAL	COMPLEXITY FACTOR	MTBF FORECAST	FAILURE RATE
97A-D	A-7D	2239	1.0	2239	.000447

97XXX - MATURE FORECAST - 2239 HRS MTBF

TABLE 24

WUC 41XXX - AIR CONDITIONING (ECS)

A-10 UNC	COMPARABLE SUBSYSTEM	COMPARABLE ACTUAL	COMPLEXITY FACTOR	MTBF FORECAST	FAILURE RATE
41A	-	-	-	included in all others	
41B	-	-	-	142	.00704
41C	-	-	-	563	.00178
41D	-	-	-	6125	.00016
41E	-	-	-	907	.00110
41F	-	-	-	7538	.00013
41XXX	OU-10	98	1.0	98	.01020

MATURE FORECAST - 98 HRS MTBF

TABLE 25

WUC 42XXX - ELECTRICAL SYSTEM

A-10 UNC	COMPARABLE SUBSYSTEM	COMPARABLE ACTUAL	COMPLEXITY FACTOR	MTBF FORECAST	FAILURE RATE
42A	-	-	-	105	.00952
42B	-	-	-	773	.00129
42C	A-7D	634	2.0	317	.00315
42D	-	-	-	1246	.00080
42E	-	-	-	185	.00541
42F	A-7D	372	2.0	186	.00538
42G				2417	.00041
	42XXX - MATURE FORECAST-39 HRS MTBF				.02596

TABLE 26

WUC 46XXX - FUEL SYSTEM

A-10 UNC	COMPARABLE SUBSYSTEM	COMPARABLE ACTUAL	COMPLEXITY FACTOR	MTBF FORECAST	FAILURE RATE
46A	-	-	-	320	.00313
46B	-	-	-	628	.00159
46C	-	-	-	533	.00188
46D	A-7D	159	1.0	159	.00629
46E	-	-	-	207	.00483
46F	-	-	-	327	.00306
46G	-	-	-	458	.00218
46XXX	F-5 A/B	1.2			.02296

MATURE FORECAST-49 HRS MTBF

TABLE 27

WUC 51XXX - INSTRUMENTS

A-10 UNC	COMPARABLE SUBSYSTEM	COMPARABLE ACTUAL	COMPLEXITY FACTOR	MTBF FORECAST	FAILURE RATE
51A	-	-	-	613	.00163
51C	-	-	-	67	.01493
51E	-	-	-	511	.00195
51F	F-111A	94	1.0	94	.01064
51G	-	-	-	305	.00328
51J	A-7D	1269	1.0	1269	.00078
	51XXX - MATURE FORECAST-30 HRS MTBF				.03321

TABLE 28

WUC 72XXX - RADAR NAVIGATION

A-10 UNC	COMPARABLE SUBSYSTEM	COMPARABLE ACTUAL	COMPLEXITY FACTOR	MTBF FORECAST	FAILURE RATE
72A	F-4 (comb)	1100	1.0	1100*	.00091

MATURE FORECAST - 1100 HRS MTBF

* The assumption here is that usage (% operating time) is equivalent on A-10.

TABLE 29

SUMMARY INITIAL MTBF FORECASTS

WUC	SUBSYSTEM	INITIAL MTBF FORECAST
11	AIRFRAME	7
12	COCKPIT	25
13	LANDING GEAR	6.5
14	FLIGHT CONTROLS	10.5
23	PROPULSION	5.4
24	APU	-
41	AIR COND	40
42	ELECTRICAL	25
44	LIGHTING	13
45	HYDRAULICS	15
46	FUEL	29
47	OXYGEN	91
49	MIS. UTILITIES	58
51	INSTRUMENTS	22
52	AUTO PILOT (SAS)	105
55	MALF EQUIP	-
62	VHF COMM	61
63	UHF COMM	46
64	INTERCOM	147
65	IFF/SIF	146
71	TACAN	55
72	RADAR NAV	-
74	FIRE CONTROL	15
75	WEAPON DELIVERY	10.3
76	ECM	-
91	EMERGENCY EQUIP	-
96	PER/MISC EQUIP	-
97	EXPLOSIVE DEVICES	-
TOTAL	A-10A AIRCRAFT	.85

TABLE 30

MATURE AIRCRAFT COMPARISIONS

AIRCRAFT	MATURE MTBF	SOURCE OF DATA
F-111A	.69	JUN 75 - 6 LOG
F-15A	.71*	DEC 75 - 6 LOG
F-4E	.83	JUL 75 - 6 LOG
A-7D	1.20	JUN 75 - 6 LOG
A-10A	1.50	FORECAST
A-37	2.50	JUN 75 - 6 LOG

* NOT A MATURE VALUE

PART II - OPERATIONAL MAINTENANCE (MMH/FH)

1. Introduction

The forecasting of MMH/FH values is a more complicated task than was MTBF. The MMH/FH parameter must be carefully defined before predictions can be generated. In general, the MMH/FH parameter is a function of the frequency of the task, the task time, and the number of people performing the task. The frequency of a given task or group of tasks may or may not include certain categories of discrepancies such as those caused by operator or maintenance error or foreign objects. The task times used may or may not include time to travel to and from the work center and the work site, or time to acquire special tools or replacement parts. The crew size value may or may not include individuals engaged in on-the-job training.

MMH/FH is more than just a function of hardware design, installation, and operation as is reliability. Other factors which do influence MMH/FH are:

- Characteristics of maintenance personnel
  - knowledge
  - experience
  - technical skill
  - attitude
- Using command influences
  - minimum crew size requirements
  - allocation of personnel
  - training programs
  - maintenance procedures

- Interface with

  AGE

  test equipment

  tools

  tech manuals

  facilities

To predict how each of these factors directly affects a MMH/FH value would be impractical at best. Therefore, the approach used in this report was to use, whenever possible, historical data from other aircraft which already reflects the impact of the above factors. Historical data from TAC-maintained aircraft was used rather than SAC or MAC-maintained aircraft. Where historical data from other aircraft was not available, data from the A-10 flight test program was used. Of the six DT&E aircraft, only one aircraft was maintained entirely by USAF personnel. Whenever possible, data from this aircraft alone was used as a basis for support general tasks. For example, task time predictions for recurring actions such as servicing and preflight/post flight/thru-flight inspections were developed from test data on the TAC-maintained aircraft. Where existing historical or test data was not sufficient, parametric analysis and/or personal experience was used.

It should be noted the title of this part of the report is operational maintenance and not maintainability. Maintainability is strictly a function of the design of the hardware. MMH/FH parameter, as was explained in previous paragraphs contains much more than pure maintainability. It is felt that the difference between the two terms is significant enough to mention here.

The MMH/FH forecasts presented in paragraphs 2 and 3 were divided into three categories:

Support General

Non-Support General

Other

Support General refers primarily to maintenance resulting from requirements other than hardware failures. Below is a listing of the Support General work unit codes (WUC's) which are used to identify the majority of Support General maintenance tasks:

WUC	TASK CATEGORY
01000	Ground handling, servicing, and related tasks
02000	Aircraft cleaning
03000	Scheduled inspections
04000	Special inspections
05000	Preservation, depreservation, and storage
06000	Arm, dearm, safety
07000	Records documentation
09000	Shop support general

For a more detailed description of the tasks within the general categories above, see T.O. 1A-10A-06.

The Non-Support General tasks are those related to malfunctions or discrepancies of the aircraft, its subsystems, and components. Forecasts were developed at the two-digit level, e.g., 13XXX, landing gear subsystem.

The third category includes cannibalization and TCTO actions. Forecasts for these items were made at the system level.

The following definitions and assumptions apply throughout paragraphs 2 and 3.

(A) Frequency of maintenance task

(1) For support general tasks, the frequency is based on requirements stated in USAF maintenance and maintenance management publications. Example: Phased inspections are accomplished at 100 hour intervals IAW T.O. 1A-10A-6.

(2) For Non-Support General tasks the frequency is equal to the expected number of Type 1 and 2 failures as defined by AFLCM 66-15.

(3) Frequencies for TCTO and cannibalization tasks are separate from (1) and (2) above and include all actions expected.

(B) The task time interval begins when an individual(s) is dispatched to perform a task and ends when the task and documentation of same is completed. Only extensive delay periods are excluded.

(C) Crew sizes were established primarily by TAC maintenance personnel and thus are representative of those normally encountered in the field.

(D) All calculations were based on a 72 aircraft wing

1800 FH/MO/wing

25 FH/A/C/MO

5 day/wk operation

21.7 days/mo for maintenance

20 days/mo for flying

50% turnaround for second flight of day

10% over schedule for morning flight

2.0 hr sorties

Periodic/recurring inspections per -6

50% missions are gun missions

100 rounds/gun sortie

2. Mature MMH/FH Forecast Methodology

2.A Support General Forecasts

The following paragraphs provide the detailed information used in the derivation of the mature support general maintenance manhours per flight hour.

2.A(1) WUC 01000 - Ground Handling, Servicing, and Related Tasks

The major contributors to the 01000 WUC are towing, jacking, launch and recovery of the aircraft. Munitions maintenance handling was purposely left out of this forecast.

(a) Towing - Aircraft are towed from the flight line to the following areas and then are returned to the flight line:

AREA	ESTIMATED FREQUENCY (events/month/wing)
Aircraft test cell	22
Phased inspection	18
Aircraft wash rack	72
TOTAL	112

The estimated round trip task time is estimated at 1.0 hours. The crew size required is 5 men. Therefore,

$$\frac{112EV/MO \times 1.0MH/EV \times 5}{1800\ FH/WING/MO} = .311\ MH/FH$$

(b) Jacking - The primary reason to jack the aircraft is due to landing gear malfunctions, other than tire changes.

Frequency	-	.06
Crew Size Required	-	4
Task Time	-	1.5 hrs

Result: .06/FH X 1.5 MH X 4 = 0.35 MH/FH.

(c) Launch (including end of runway check):

Frequency	-	0.5/FH
Crew Size Required	-	1

Task Time Required - 1.2 hrs (based on DT&E data - A/C #5)

Result: 0.5/FH X 1 X 1.2 hrs = 0.60 MMH/FH

(d) Recovery (including fuel and oil servicing):

Frequency	-	0.50/FH
Crew Size Required	-	1
Task Time	-	1.5 hrs (based on DT&E data)

Result: 0.50/FH X 1 X 1.5 hrs = 0.75 MMH/FH

Summary - WUC 01000:

	TASK	MMH/FH
(a)	Towing	0.31
(b)	Jacking	0.36

(c)	Launch	0.60
(d)	Recovery	0.75
TOTAL	- 01000	2.02

2.A(2) WUC 0200 - Washing, Cleaning, Corrosion Prevention Treatment and Decontamination. The major contributors to the 02000 WUC are aircraft wash, engine wash and windshield wash.

(a) Aircraft Wash

Frequency - 72/MO

Crew Size - 3

Task Time - 5 hrs

Results: $\frac{\text{72/MO X 5 hrs X 3}}{\text{1800 FH/MO}}$ = 0.60 MMH/FH

(b) Engine Wash

Frequency - 72/MO

Crew Size - 3

Task Time - 3 hrs

Results: $\frac{\text{72 X 3 X 3}}{\text{1800}}$ = 0.36 MMH/FH

(c) Windshield Wash (required after each gun firing mission)

Frequency - 0.25/FH

Crew Size - 1

Task Time 1.0 hr

Results: 0.25/FH X 1 X 1 hr = 0.25 MMH/FH

Summary - WUC 02000:

TASK	MMH/FH
Aircraft Wash	0.60
Engine Wash	0.36
Windshield Wash	0.25
TOTAL - 02000	1.2

2.A(3) WUC 03000 - "LOOK PHASE" of Scheduled Inspections

The major contributors to the 03000 WUC are preflight inspections, basic postflight/thruflight inspections, hourly post flight inspections and phased inspections.

(a) Preflight/Postflight/Thruflight Inspections - The following frequencies are based on:

10% overschedule for morning sorties

50% turnaround for afternoon sorties

20 flying days per month

$$\frac{1800\ \text{FH/MO}}{20\ \text{day/MO} \times 2.0\ \text{hr sorties}} = 45\ \text{sorties/day/wing}$$

The 45 sorties are allotted as follows: 30 morning sorties (requiring 33 preflight inspections) and 15 afternoon sorties. Therefore, the total number of inspections/day is:

33 - Preflight (PR)

15 - Thruflight (TH)

30 - Basic Postflight (BPO)

5 - Hourly Postflight (HPO)

The values from these three methods were then subjectively combined to form the following forecasts:

Preflight	-	0.9 MMH/FH
Basic Postflight	-	1.5 MMH/FH
Thruflight	-	0.1 MMH/FH

(b) Phased Inspections - As of the time of the initial report to OSD, only six phased inspections had been accomplished. Of those six, one was considered not representative (too few manhours). Thus, data from only five phased inspections was used. The average manhours for those five inspections was 55 MMH. Since these were direct manhours, additional manhours were added to account for time spent traveling to and from the work center, acquiring tools, tech data, and supplies, and documenting the maintenance performed. Also, since only the first two of six phased inspection packages were accomplished, additional manhours were added to account for possible more extensive inspection. After considering these additional factors, the resulting maintenance expenditure was estimated at 63 MMH. For a 100 FH phased inspection interval, the maintenance expenditure then becomes 0.6 MMH/FH.

Due to the small DT&E data base a second forecast method was used as a check. Based on historical data from other similar aircraft, Figure 1 was constructed. The results indicate that given the non-support general MMH/FH for an aircraft, an estimate of the phased inspection MMH/FH can be extracted from the graph. The A-10 estimate for the phased inspection is 1.8 MMH/FH. Note that this value is significantly larger than that derived from DT&E data (0.6 MMH/FH). However, since both methods of forecasting are considered valid, results from both were combined to arrive at a single forecast of 1.0 MMH/FH.

<u>Summary - WUC 03000</u>:

TASK	MMH/FH
Preflight	0.9
Basic Postflight	1.5
Hourly Postflight	0.1
Phased	1.0
TOTAL	3.5

2.A(4) WUC 0400 - Special Inspections -

Only extremely limited DT&E data was available on special inspections; therefore, the graphical technique previously used to provide inputs for forecasting scheduled inspections MMH/FH was used as the primary tool (See Figure 3). Result: 1.6 MMH/FH.

2.A(5) WUC 05000 - Preservation and Depreservation of Equipment -

Data on manhours spent preserving/depreserving components was not available at the time of the study. Therefore, the 0.1 MMH/FH forecast is essentially an estimate of the order of magnitude for this WUC.

2.A(6) WUC 06000 - Arming, Disarming and Ground Safety -

The frequency for arm/dearm was based on an estimate that 50% of all sorties would be gun and/or weapons release sorties. A crew size of two and an average task time of 1.0 hours was assumed for a resulting 0.5 MMH/FH.

Three different methods were used to predict MMH/FH for three of the above inspections.

Method 1:

Data from a maintenance task team study accomplished in October 1975 resulted in the following MMH/FH values:

WUC	TASK	FREQ	TASK TIME	CREW SIZE	MMH/FH
03100	PR	.37/FH	1.6	2	1.17
03200	TH	.17/FH	0.8	2	0.27
03210	BPO	.33/FH	2.5	2	1.67

Method 2:

Data from the TAC maintained DT&E aircraft resulted in the following values:

WUC	TASK	FREQ	MH/TASK	MMH/FH
03100	PR	.37	2.5	.92
03200	TH	.17		
03210	BPO	.33	2.3	1.15

Method 3:

This third method was based on a review and comparison of historical data. (See Figures 1, 2, 3, and Table 31)

Preflight	-	0.8 MMH/FH
Basic Postflight	-	1.4 MMH/FH

TABLE 31

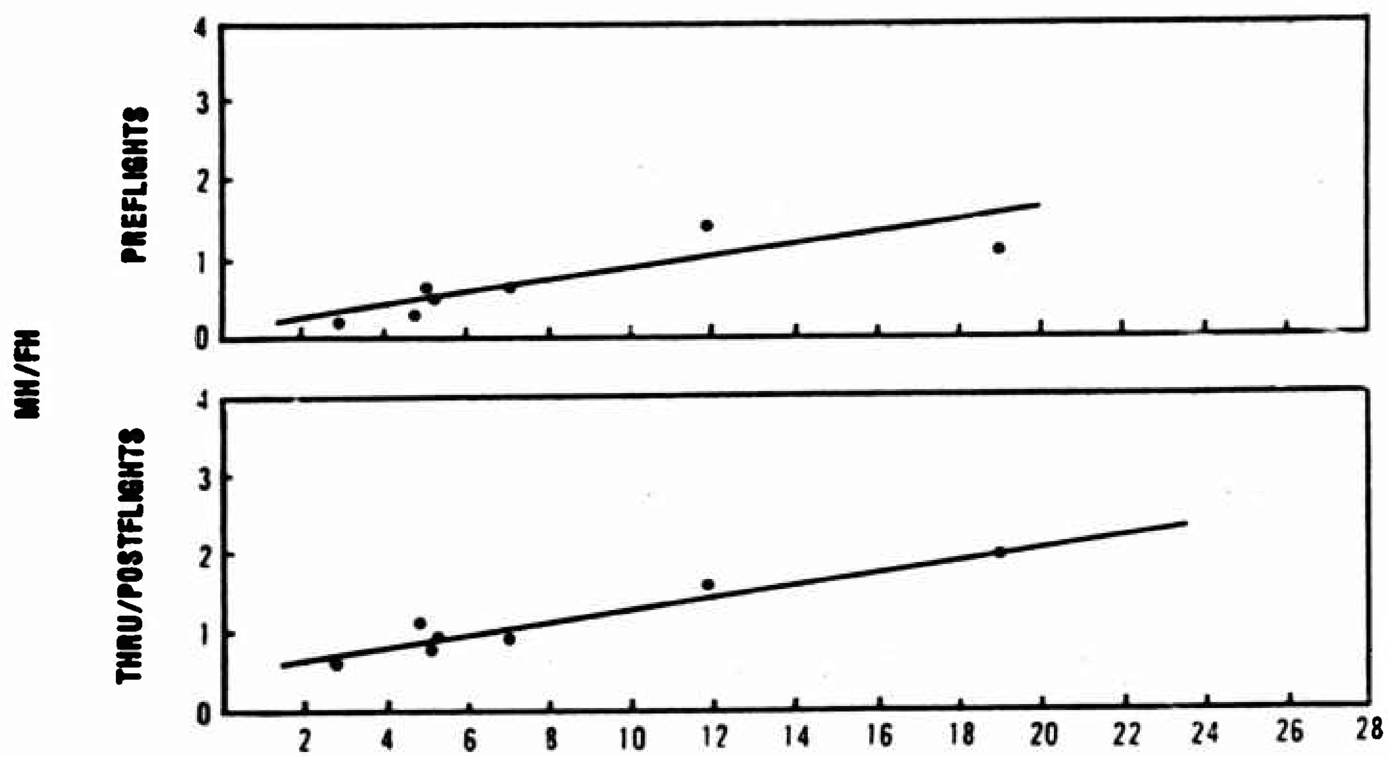
SOURCE DATA FOR FIGURES 1, 2 & 3

AIRCRAFT	MMH/FH				
	WUC 11-99	PREFLIGHT INS	THRU & POSTFL INS	SPECIAL INS	PHASED INS
T-37	2.7	.2	.6		.7
T-38	4.6	.3	1.1		1.5
T-39	5.1	.6	.8		.3
A-37	5.3	.5	.9		1.1
OV-10	7.0	.6	.9		1.0
A-7	11.8	1.4	1.6		1.6
F-4E	19.2	1.1	2.0		3.1

SOURCE: 25LOGK261, 12 MOS. ENDING JUL 75

HISTORICAL DATA

PREFLIGHT, THRUFLIGHT AND POSTFLIGHT INSPECTIONS



MMH/FH - WUC's 11-99 (CORRECTIVE MAINTENANCE)

FIGURE 1

HISTORICAL DATA - PHASED INSPECTIONS

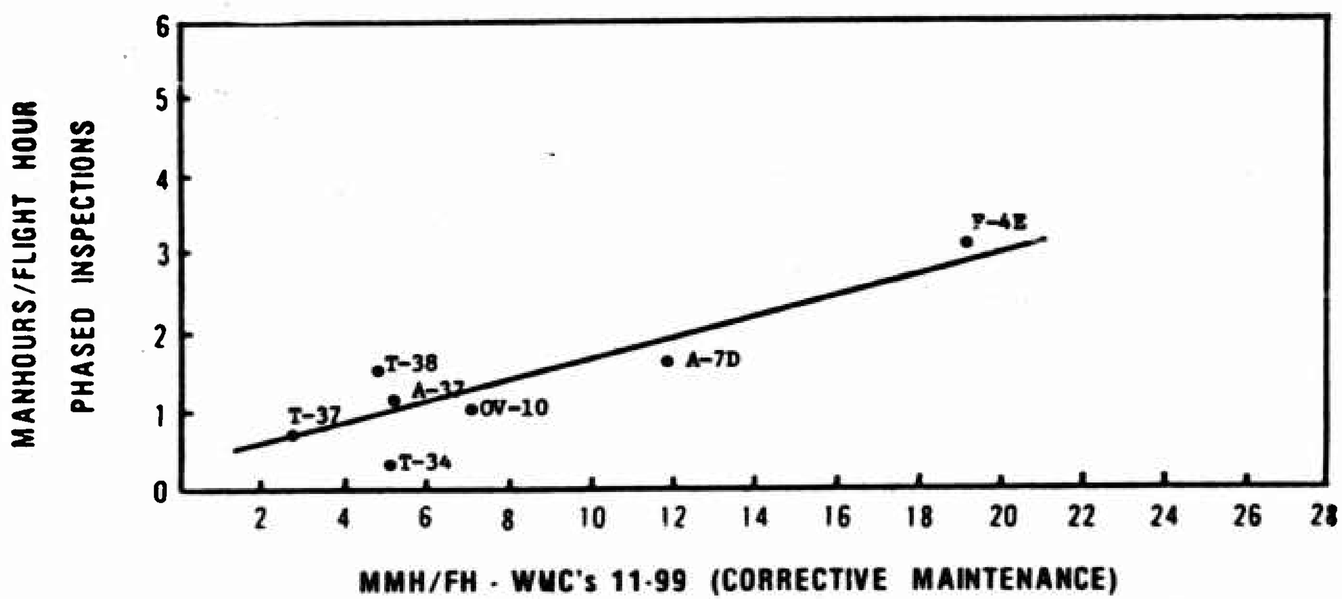


FIGURE 2

SOURCE: 25 LOGK261, 12 MO. ENDING 25 JUL

HISTORICAL DATA - SPECIAL INSPECTIONS

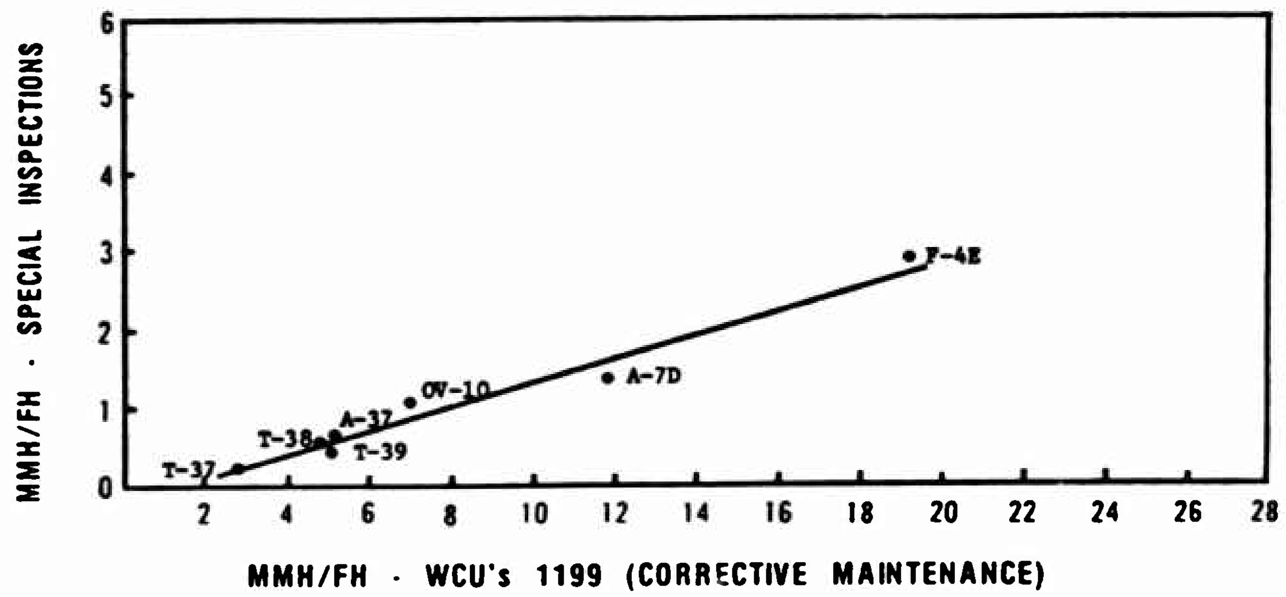


FIGURE 3

SOURCE: 25 LOGK261, 12 MO. END JUL 75

2.A(7) WUC 07000 - Preparation and Maintenance of Records and Publications -

WUC 07000 is used to record only direct labor expended in preparation and/or maintenance of status and historical forms. Manhours expended in the preparation of production documentation forms (AFTO Forms 349 and 350) are included as part of the maintenance task being accomplished and thus are not recorded separately. Historical data for WUC 07000 was not available at the time of the study; therefore, the 0.1 MMH/FH forecast is essentially an estimate of the order of magnitude for this WUC.

2.A(8) WUC 09000 - Shop Support -

Shop support general consists of the following in-shop maintenance tasks:

(a) Fabricate - includes bending, cutting, forming, casting, holding, machining, soldering, assembly, local manufacture, etc. Does not include a part of a fix on a specific job.

(b) Painting - including stenciling, lettering, installing decals, instrument range marking, etc. Does not include treatment of corroded items.

(c) Engine and/or Power Pack Build-up or Teardown - Engine Operation in Test Stand - includes installation of engine in test stand.

(d) Wheel and Tire Build-up and Teardown - Cleaning and/or Servicing - includes recharging, sand-blasting, degreasing, preparation for and/or removal from storage or shipment, etc.

(e) Inspection and/or Repack of Parachutes - includes all types.

(f) Inspection and/or Repack of Flotation Equipment - Inspection of Personal Equipment - includes helmets, specialized flight suits, etc.

(g) Plating - includes cleaning and preparation for plating.

The majority of the above tasks are accomplished as a result of on-aircraft events. Manhours for the shop actions relating to these events should be included in the task time predictions for the individual subsystems and not shown as part of WUC 09000. However, since the AF MDC directs that shop support general manhours be coded to WUC 09000, manhours which really belong to subsystem WUC's were extracted from those WUC's and included in 09000 WUC. The following forecasts are considered the most significant within this WUC.

Wheel and Tire Build-up (from 13XXX):

Frequency	=	.05/FH
MMH/TASK	=	4.0 MMH
MMH/FH	=	0.20

Engine Build-up (from 23XXX):

Frequency	=	.008/FH
MMH/TASK	=	30 MMH
MMH/FH	=	.24

Battery Capacity Check (from 42XXX):

Frequency	=	.04/FH (every 30 days)
MMH/TASK	=	4 MMH
MMH/FH	=	.16 MMH/FH

Other:

0.1 is an order of magnitude estimate.

Summary - WUC 09000:

TASK	MMH/FH
Wheel & Tire Build-Up	.20
Engine Build-up	.24
Battery Capacity Checks	.16
Other	.10
TOTAL - 09000	.70

Table 32 is a summary of the mature support general MMH/FH forecasts.

2.B Non-Support General Forecasts

The non-support general MMH/FH predictions were based on the following information:

(a) Frequencies of Type 1 failures (MTBF) developed in Part 1 of this section of the report.

(b) Ratios of Type 2 to Type 1 failures based on historical data (see Table 34).

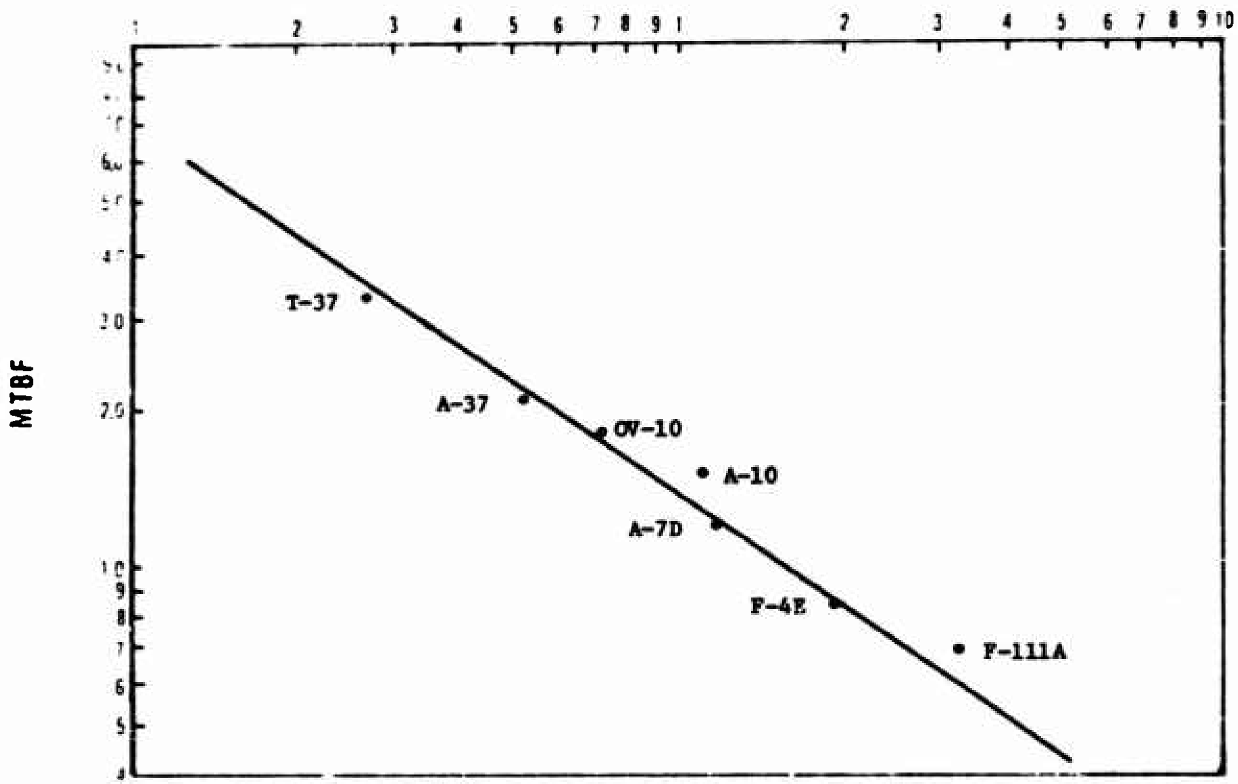
(c) Manhour per maintenance action (MH/MA) information generated by a joint ASD/JTF/TAC analysis team in October 1975. This was accomplished as part of the maintenance manpower personnel update to the A-10 data base for manpower planning.

(d) Ratios of off-aircraft to on-aircraft maintenance based on historical data (See Table 33).

Table 34 is a summary of the results of this forecast.

Figure 4 is a historical comparison of the A-10 forecast against other Air Force aircraft.

MTBF/NON-SUPPORT GENERAL MMH/FH CORRELATION



NON-SUPPORT GENERAL MMH/FH (25 LOG K 261)

FIGURE 4

TABLE 32

SUPPORT GENERAL SUMMARY

WUC	TASKS	MMH/FH
01000	Ground Handling	1.85
02000	Washing, Cleaning	1.15
03000	Scheduled Inspection	3.50
04000	Special Inspections	1.40
05000	Preservation	0.10
06000	Arm - Dearm	0.50
07000	Records Documentation	0.10
09000	Shop Support General	0.70
	TOTAL - SUPPORT GENERAL	9.30

TABLE 33

SHOP VERSUS ON/AC MMH

A-10 WUC	A-7	A-37	F-4E	T-38	OTHER		EST A-10
11	.15	.25	.09	.14			.15
12	.16	.17	.07	.15			.15
13	.77	.50	.45	.53			.5
14	.15	.21	.08	.32			.15
23 Eng	-	-	.19	-	.36	TF-33	.3
Start	-	-	.2	-	.85	F-111A	.3
Instr	.12	-	.2	-	.32	C-141	.2
Contr	.03	-	-	-	.03	C-141	.03
24 APU	-	-	-	-	.2	C-141	.2
Instr	-	-	-	-	.21	C-141	.2
41	.08	.04	.10	.23			.1
42	1.6	2.0	.44	1.4			.5
44	.17	.12	.07	.61			.15
45	.17	.17	.12	.48			.15
46	.15	.10	.60	.18			.15
47	.16	.08	.21	.14			.15
49	0	.02	0	.02	.24		.2
51 (51F)	.11	.13	.35	.26	.65	F-111	.26
52	-	-	-	.41			.5
55	-	0	0	.1			.05
62	1.6	1.4					1.5
63	1.2	1.0		1.8			1.5
64	.36	.55		.15			.5
65	1.0	1.1		1.0			1.0
71	1.9	1.6	1.2	1.8			1.7
72	-	0	1.4				1.4
74A HUD	1.2		1.4				1.3
74C							1.5*
74E							1.5*
75A Gun	.5	.25	.75				.5
75B	.34	.5					.4
75C	1.4						1.4
76	-	-	.36				.4

*Est.

TABLE 34

NON-SUPPORT GENERAL SUMMARY

WUC	MATURE MTBF	TYPE 2 / TYPE 1 RATIO	FREQUENCY MA/FH [$\frac{1}{(1)}$ X (2)]	MH/MA ACTUALS USED IN FORECAST	ON AIRCRAFT MH/FH USED IN FORECAST [(3) X (4)]	OFF A/C / ON A/C RATIO	OFF AIRCRAFT MH/FH FORECAST [(5) X (6)]	TOTAL MH/FH FORECAST [(5) + (7)]
11	15	3.0	.200	3.2	.64	.15	.10	.74
12	64	2.0	.031	5.3	.17	.15	.03	.20
13	17	1.4	.082	7.5	.32	.5	.16	.48
14	13	1.4	.108	9.5	1.10	.15	.17	1.27
23	12	1.3	.108	15.2	1.58	.3E	.39	1.97
24	28	1.2	.043	6.2	.27	.2	.05	.32
41	98	1.4	.014	8.9	.13	.1	.01	.14
42	39	1.4	.036	7.9	.28	.5	.14	.42
44	37	1.25	.034	3.1	.10	.15	.02	.12
45	43	1.3	.030	8.1	.24	.15	.04	.28
46	49	1.4	.029	13.0	.37	.15	.06	.43
47	91	1.3	.014	6.0	.09	.15	.01	.10
49	150	1.4	.009	11.1	.10	.2	.02	.12
51	30	1.2	.040	9.9	.39	.2E	.13	.52
42	105	1.1	.010	5.3	.06	.5	.03	.09
55	503	1.2	.002	6.0	.01	.05	.01	.02
62	61	1.1	.018	4.6	.08	1.5	.12	.20
63	54	1.1	.020	3.9	.08	1.5	.12	.21
64	147	1.2	.008	4.5	.04	.5	.02	.06
65	154	1.1	.007	6.8	.05	1.0	.05	.10
71	122	1.1	.009	5.2	.05	1.7	.09	.14
72	1100	1.1	.001	8.2	.01	1.4	.01	.02
74	18	1.06	.059	6.4	.39	1.4E	.54	.93
75	20	1.5	.075	10.3	.84	1.0E	.63	1.47
76	206	1.3	.006	8.4	.05	.4	.02	.07
91	226	-	-	-	-	-	-	.10
96	9896	-	-	-	-	-	-	.01
97	2239	-	-	-	-	-	-	.04
TOT			.993		7.44		2.97	10.56

3. Initial MMH/FH Forecast Methodology

An initial value of MMH/FH was desired. Initial was defined as the first full three months of operation after site activation. Since site activation occurred in March 1976 the April through June 1976 time frame was defined as the initial time period for which forecasts were desired.

The method used to forecast these initial values of MMH/FH was based primarily on actual A-10A DT&E flight test data. The technique was to develop basic system level forecasts for Support General and Non-Support General maintenance. These basic forecasts were factored to account for learning and reliability growth as applicable.

3.A Initial Support General Forecast

The mature value of MMH/FH forecasted for Support General maintenance was generated based on historical data at that particular point in time from many different aircraft. Additionally, the task times used were verified by the using command as reasonable estimates. It was therefore decided to use the mature Support General forecasts as the basic system level forecast and adjust that value to account for learning and/or lack of knowledge of the maintenance personnel. This learning should be expected upon any initial site activation. The learning factors were developed by a joint ASD/TAC/AFTEC evaluation team. The team relied heavily upon early F-15 experience. The application of these subjective learning factors accounted for a fifty percent increase in the MMH/FH for Support General. Table 35 shows the quantitative values used in developing this initial value of MMH/FH.

TABLE 35

LEARNING FACTORS USED

	SUPPORT GENERAL	NON-SUPPORT GENERAL
APR	1.5	1.5
MAY	1.5	1.5
JUN	1.3	1.4
JUL	1.1	1.4
AUG	1.1	1.3
SEP	1.1	1.3
OCT	1.1	1.2
NOV	1.1	1.2
DEC	1.1	1.1

3.B Initial Non-Support General Forecast

The Non-Support General initial forecast was based both on A-10 DT&E flight test data and mature task time forecasts previously established. The June through December 1975 maintenance data was used for this evaluation. The frequency of maintenance actions from this DT&E data base showed 1.9 maintenance actions per flight hours (MA/FH). Maintenance action were defined at Type 1 plus Type 2 failures. The average manhours per maintenance action (MH/MA) for the entire A-10 aircraft was forecasted by the manpower people as 7.6 MH/MA. This resulted in

$$1.9 \text{ MA/FH} \times 7.6 \text{ MH/MA} = 14.4 \text{ MH/FH}$$

for the on-aircraft portion of Non-Support General maintenance. The off-aircraft Non-Support General maintenance was based on a ratio of off-aircraft to on-aircraft maintenance developed from historical data on existing fighter-type aircraft. The resulting ratio was .39. Therefore, the off-aircraft MMH/FH is obtained by the following:

$$14.4 \text{ MMH/FH} \times (.39) = 5.6 \text{ MMH/FH}$$

Consequently, the total Non-Support General MMH/FH was the sum of the on-aircraft and off-aircraft MMH/FH:

On-aircraft	-	14.4 MMH/FH
Off-aircraft	-	5.6 MMH/FH
Total		20.0 MMH/FH

This value was used as the basic Non-Support General forecast for initial site activation. This value was factored upward to account for two things - learning and reliability growth. Both the learning factors and reliability factors were developed using subjective criteria and were only educated guesses based on personal experiences. Table 36 shows the results.

4. Results

Table 37 is a summary of the A-10 MMH/FH forecasts for both the initial and mature time frames. A comparison of these forecasts with other aircraft was accomplished. Table 38 shows the relationship of the mature A-10 MMH/FH forecast with other TAC matured aircraft in the Air Force inventory. The results appear to validate the methodology developed.

TABLE 36

APPLICATION OF LEARNING FACTORS TO MMH/FH FORECASTS

A-10 MMH/FH PREDICTION - APR - DEC 1976

- BASIC PREDICTIONS
  - SUPPORT GENERAL 10 MMH/FH
  - NON-SUPPORT GENERAL 20 MMH/FH
- FACTORS AND ADJUSTED PREDICTIONS

MONTH	CUM FH	SUPPORT GENERAL (1)	SUPPORT GENERAL ADJUSTED	NON-SUPPORT GENERAL (1)	NON-SUPPORT GENERAL (2)	NON-SUPPORT GENERAL ADJUSTED	CAN & TCTO	TOTAL
APR	125	1.5	15	1.5	1.00	30	2	47
MAY	275	1.5	15	1.5	0.98	29	2	46
JUN	450	1.3	13	1.4	0.97	27	2	42
JUL	650	1.1	11	1.4	0.95	27	2	40
AUG	875	1.1	11	1.3	0.93	27	2	40
SEP	1150	1.1	11	1.3	0.92	24	2	37
OCT	1475	1.1	11	1.2	0.91	22	2	35
NOV	1850	1.1	11	1.2	0.89	21	2	34
DEC	2275	1.1	11	1.1	0.87	19	2	32

(1) LEARNING CURVE FACTOR

(2) RELIABILITY GROWTH FACTOR

TABLE 37

SUMMARY

A-10 MMH/FH FORECASTS

	INITIAL	MATURE
SUPPORT GENERAL	15	10
NON-SUPPORT GENERAL	28	11
OTHER MAINT.	2	1
TOTAL	45	22

* VALUES WERE ROUNDED

TABLE 38

AIRCRAFT COMPARISON - MATURE SYSTEMS

AIRCRAFT	MMH/FH	SOURCE
F-111A	60	K-14 Report
F-15A	47*	58 TFTW
F-4E	37	K-14 Report
A-7D	22	K-14 Report
A-10A	22	Prediction
A-37	13	K-14 Report

* Not Mature System

SECTION III

EXPERIENCE: OBSERVED R&M VALUES VERSUS INITIAL FORECASTS

1. INTRODUCTION

The objective of this report is to provide a forecasting technique for other acquisition organizations. However, to provide an unproven technique would not provide the most benefit. Consequently, it was decided to withhold publishing this technique until adequate time had passed to prove or disprove the method. This section is designed to provide a comparison of the MTBF and MMH/FH forecasted for the April-June 1976 time frame with those values actually observed/measured in the operational environment.

2. OPERATIONAL HARDWARE RELIABILITY (MTBF)

The method used to forecast the initial value of MTBF is provided in Section II, Part I, paragraph 3, of this report. Table 39 is a summary of the system level (2-digit WUC) initial forecasts and the MTBF's actually observed during the first three months of A-10 operation at Davis-Monthan AFB, Arizona. As can be seen, the observed values are significantly higher than forecasted. However, upon detailed analysis of the subsystems a specific trend can be seen. When you analyze the initial forecast, the ten lowest subsystems, from a MTBF standpoint, account for over 80% of the total failure rate of the aircraft. In comparison, the ten lowest MTBF subsystems from observed data account for over 75% of the actual measured failure rate. The ten subsystems in question are also identical in each case. Table 40 shows the failure rate ranking of these ten subsystems.

TABLE 39

SUBSYSTEM MTBF - ACTUAL VS. FORECAST

FORECASTED VS. ACTUAL

SUBSYSTEM WUC	FORECASTED	ACTUAL
11 - AIRFRAME	7	33
12 - COCKPIT	25	36
13 - LANDING GEAR	6.5	8.3
14 - FLIGHT CONTROLS	10.5	11.9
23 - PROPULSION	5.4	14.7
24 - APU	-	62
41 - AIR COND.	40	71
42 - ELECTRICAL	25	19
44 - LIGHTING	13	45
45 - HYDRAULICS	15	18.5
46 - FUEL	29	62
47 - OXYGEN	91	249
49 - MISC. UTILITIES	58	249
51 - INSTRUMENTS	22	42
52 - AUTO PILOT (SAS)	105	45
55 - MALF EQUIP	-	NF*
62 - VHF COMM	61	100
63 - UHF COM	46	55
64 - INTERCOMM	147	499
65 - IFF/SIF	146	166
71 - TACAN	55	42
72 - RADAR NAV	-	NF*
74 - FIRE CONTROL	15	28
75 - WEAPONS DELIVERY	10.3	22
76 - ECM	-	499
91 - EMERGENCY EQUIP	-	499
96 - PER/MISC EQUIP	-	NF*
97 - EXPOL. DEVICES	-	NF*

TABLE 39

SUBSYSTEM MTBF - ACTUAL VS. FORECAST

FORECASTED VS. ACTUAL

SUBSYSTEM WUC	FORECASTED	ACTUAL
A-10A	.85	1.39

* NO FAILURE

TABLE 40

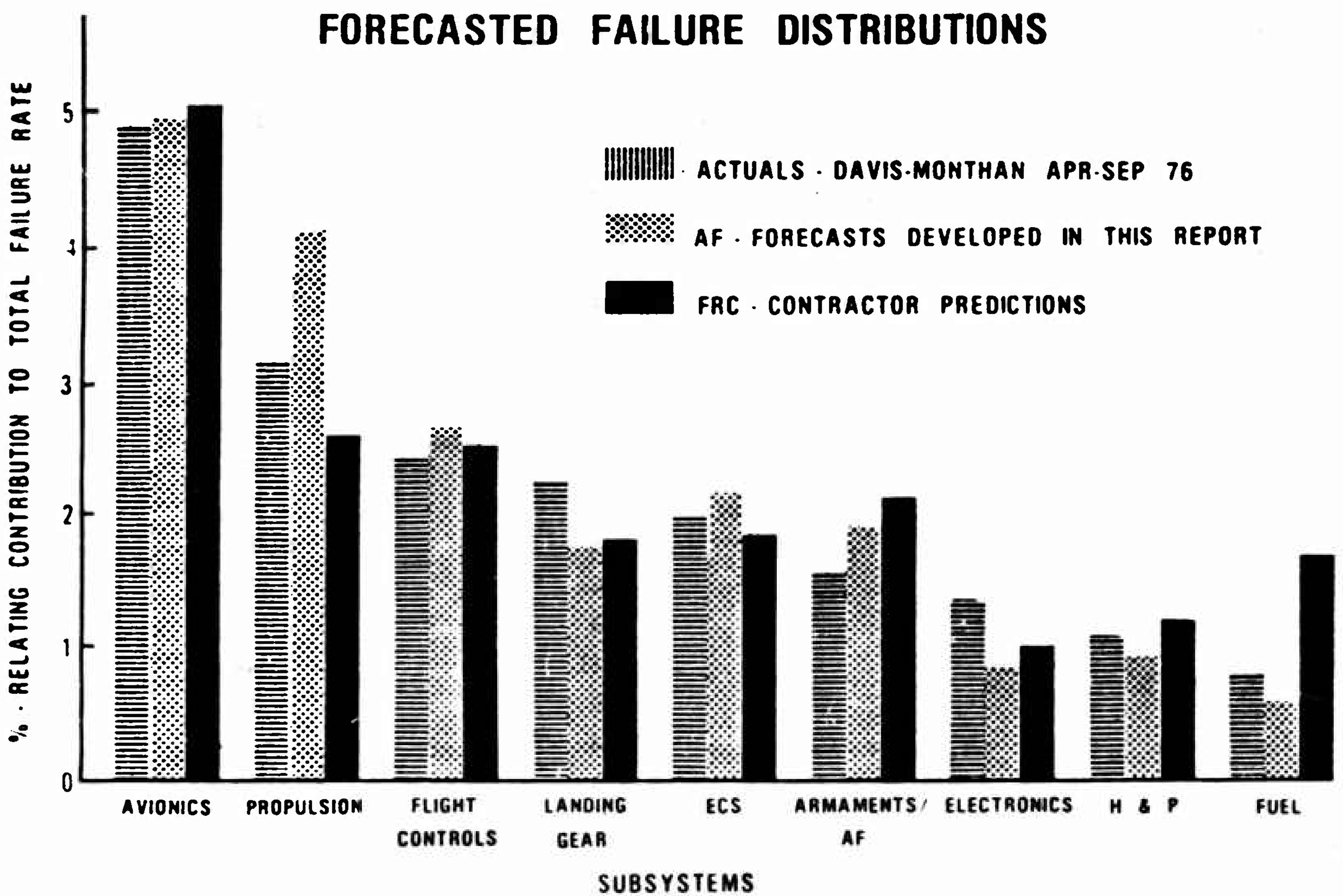
FAILURE RATE RANKING - ACTUAL VS. FORECAST

JUNE 76 FORECAST			ACTUAL VALUE		
RANK	SUBSYSTEM-WUC	%	RANK	SUBSYSTEM-WUC	%
1	23 - ENGINE	15.7	1	13 - LANDING GEAR	16.7
2	13 - LANDING GEAR	13.1	2	14 - FLIGHT CONTROLS	11.7
3	11 - AIRFRAME	12.1	3	23 - ENGINE	9.5
4	75 - WEAPONS DELIVERY	8.2	4	45 - HYDRAULICS	7.5
5	14 - FLIGHT CONTROLS	8.1	5	42 - ELECTRICAL	7.2
6	44 - LIGHTING	6.5	6	75 - WEAPONS DELIVERY	6.4
7	45 - HYDRAULICS	5.7	7	74 - FIRE CONTROL	5.0
8	74 - FIRE CONTROL	5.7	8	11 - AIRFRAME	4.2
9	51 - INSTRUMENTS	3.9	9	12 - COCKPIT	3.9
10	42 - ELECTRICAL	3.4	10	51 - INSTRUMENTS	3.3

Additionally, these actual values were qualitatively compared not only to the June 1976 forecast but also to contractor forecasts which were developed early in the design phase of the program. In order to accomplish this comparison the existing 2-digit WUC subsystems had to be combined to match the initial contractor definition of subsystems. (The contractor definitions of subsystems were functionally oriented plus they were defined prior to formulation of the A-10 WUC manual.) The following list shows which WUC's were combined to form the contractor subsystems:

Contractor Subsystem	WUC's Included
Avionics	51, 62, 63, 64, 65, 71, 72, 74
Propulsion	23, 24
Armament	75
Flight Controls	14, 52
Environmental Control	12, 41, 44, 47
Landing Gear	13
Fuel	46
Hydraulics	45
Electrical	42

It should be noted that there exists no contractor subsystem associated with the WUC 11XXX-Airframe. Figure 5 graphically depicts the results of this analysis. Based on these analyses it was concluded that the initial forecast methodology used was qualitatively accurate. That is,


FORECASTED FAILURE DISTRIBUTIONS
ACTUALS · DAVIS-MONTHAN APR-SEP 76
AF · FORECASTS DEVELOPED IN THIS REPORT
FRC · CONTRACTOR PREDICTIONS
% · RELATING CONTRIBUTION TO TOTAL FAILURE RATE
0
1
2
3
5
AVIONICS
PROPULSION
FLIGHT CONTROLS
LANDING GEAR
ECS
ARMAMENTS/ AF
ELECTRONICS
H & P
FUEL
SUBSYSTEMS
FIGURE 5

the observed actuals showed excellent correlation with the initial forecasts from the standpoint of which subsystems were the "bad actors". The quantitative (numerical) values, however, were significantly in error. The possible explanations for this difference could have been:

Environment

Maintenance Factors

More reliable aircraft

Statistical Variance

The difference between the flight test environment at Edwards AFB and the training environment at Davis-Monthan AFB was significant. Although there was little, if any, climatic difference between the two locations (both are desert), the mission profiles were significantly different. Mission objectives were different. The Edwards operation is designed to stress the aircraft to its design limits whereas the Davis-Monthan operation is a training environment. Sorties lengths were significantly different and subsystem operation was also different.

The term maintenance factors means either a difference in the manner which maintenance tasks were performed or a difference in the maintenance personnel. Although this is traditionally a prime factor in explaining differences in maintenance data between two different locations, this effect was discounted in the case of the A-10A. The same maintenance cadre that maintained the aircraft at the flight test center at Edwards was in residence at Davis-Monthan when the first production A-10's were delivered to the using command. In addition, several data accuracy meetings were convened at both Edwards and Davis-Monthan and the quality of the data collection effort was equivalent at both locations.

The production aircraft delivered to Davis-Monthan did contain fixes for many problems encountered during the flight test program at Edwards. Consequently, these new aircraft were more reliable than the preproduction (Edwards) aircraft were highly instrumented which caused many problems not normally expected. Unqualified hardware was also used during the DT&E program. The full effect of all these problems was not, however, considered significant since credit for many of the fixes was included in the original forecast.

Statistical variance was the last possible explanation for such a quantitative difference. There is, obviously, some variance within the data. However, it was not felt that this provided the entire answer for the difference.

It is more than likely that a combination of all the above factors contributed to the difference between the observed values versus the forecasted values. As a result of this data review, the authors became involved in a detailed follow-on study which resulted in a revision to the original forecasted values. These revisions, with associated rationale is provided in Section IV of this report.

3. OPERATIONAL MAINTENANCE (MMH/FH)

The initial MMH/FH forecast was developed in Section II, Part 2, paragraph 3. The resultant forecast was 45 MMH/FH for the Apr-Jun time frame. The actual observed value at Davis-Monthan AFB was 21 MMH/FH.

As it was for operational reliability, the initial forecasts appear to be significantly in error. In fact, the observed MMH/FH was much closer to the mature forecasts than the initial forecasts. A detailed review was undertaken to determine the cause. Tables 41, 42, and 43 provide comparisons of the Support General, Non-Support General and other categories of maintenance. This review resulted in three main reasons for the difference between forecasted and observed:

Learning factors

Task times

Better reliability

The learning factors used appear, in retrospect, to be much too conservative. There are several different reasons for this. First, the maintenance personnel were essentially the same cadre of people who maintained the aircraft at the flight test center (Edwards). Consequently, there was really no need to account for learning since these people had performed most of the tasks many times prior to site activation at Davis-Monthan. Secondly, initial F-15 experience was also used in the development of these learning factors. However, the complexity and component density of the F-15 design is such that a comparison to the A-10 was highly questionable. Subsystem interfaces which require extensive troubleshooting (and learning) by different skill levels are almost nonexistent on the A-10 aircraft. Therefore, it becomes easier to understand why the

TABLE 41

MMH/FH - SUPPORT GENERAL - ACTUAL VS. FORECAST

	WUC	FORECAST	D-M ACTUAL (APR - JUN)
01	GROUND HANDLING, SERVICING	2.83	2.70
02	AIRCRAFT CLEANING	1.97	.35
03	SCHEDULED INSPECTIONS	5.10	2.58
04	SPECIAL INSPECTIONS	2.13	1.56
05	PRESERVATION	.14	-
06	ARM/DE-ARM	.71	.52
07	RECORDS DOCUMENTATION	.14	.19
09	SLOP SUPPORT (GENERAL)	1.00	.23
	TOTAL	14.00	8.13

TABLE 42

MMH/FH NON-SUPPORT GENERAL

ACTUALS VS. FORECAST

	FORECAST	ACTUALS
o ON-AIRCRAFT	9.9	5.7
o OFF-AIRCRAFT (SHOP)	4.2	2.5
o SPECIAL GUN INSPECTION	.1	-
o SPECIAL BATTERY INS.	.2	-
o COMPONENT TIME CHANGE	.1	-
o CANNIBALIZATION	.6	.5
	15.1	8.7

TABLE 43

MMH/FH

OTHER MAINTENANCE

ACTUALS VS. FORECAST

o ACTUAL TCTO MAINTENANCE

- APR	.6	MMH/FH
- MAY	1.9	MMH/FH
- JUN	5.5	MMH/FH
- JUL	.9	MMH/FH
- AUG	5.7	MMH/FH
- SEP	5.1	MMH/FH
SIX MONTH AVERAGE	3.5	MMH/FH

o FORECASTED TCTO MAINTENANCE -2.0 MMH/FH observed MMH/FH values reflect the mature values more than the initial forecasts. This may not be the case on other weapons systems or at other A-10 operational sites upon activation.

In addition to the learning factors, task times observed for several of these subsystems during this time frame were significantly lower than forecasted through the manpower study. This could be caused by many things ranging from too small a sample of tasks performed during this time frame to incorrect original estimates of time to repair. Whatever the reason, lower task times did significantly affect the observed MMH/FH values. Table 44 is a comparison of forecasted versus observed task times at the subsystem level (2-digit WUC).

The third factor considered was that the hardware reliability (MTBF) was better than anticipated. That is, the frequency with which maintenance was required was less than originally expected.

In summary, all three of the above reasons, combined to indicate a much lower maintenance expenditure than anticipated. Although this did occur on the A-10, it is not reasonable to assume a similar situation with other aircraft. In fact, it is highly probable that when more A-10A's are delivered and new maintenance personnel are assigned an increase in MMH/FH will occur. Therefore, one should tailor these types of forecasts to a particular program and consider all these variables when attempting to forecast maintenance parameters.

TABLE 44

MAINTENANCE TASK TIMES

L - COMM VS. ACTUALS

WUC	L - COMM ESTIMATE	D-M ACTUALS (APR - JUN)
11	3.2	1.7
12	5.3	8.8
13	7.5	4.6
14	9.5	6.9
23	15.2	5.7
24	6.2	2.7
41	8.9	4.4
42	7.9	1.0
44	3.1	1.4
45	8.1	5.8
46	13.0	70.3
47	6.0	6.0
49	11.1	8.1
51	9.9	4.4
55	6.0	1.3
62	4.6	2.0
63	3.9	6.0

TABLE 44

MAINTENANCE TASK TIMES

L - COMM VS. ACTUALS

WUC	L - COMM ESTIMATE	D-M ACTUALS (APR - JUN)
64	4.5	1.5
65	6.8	7.8
71	5.2	5.7
72	8.2	-
74	6.4	12.3
75	10.3	12.3
76	8.4	8.5

SECTION IV

REVISION TO ORIGINAL RELIABILITY AND MAINTENANCE FORECASTS

PART I- RELIABILITY (MTBF) REVISIONS

1. Revision to Mature Reliability Forecast (MTBF)

It was determined by the analysis in Section III of operational data that revisions to the original MTBF forecasts were required. Of the several possible factors contributing to the differences between actual values and forecast values the only one that was practical for quantitative purposes was Sortie Length. This conclusion was based on the theory that if two aircraft are dispatched and each aircraft experiences a non-mission essential failure, the aircraft that flies the longer mission will have a higher measured MTBF. This theory has been partially validated by several independent Air Force manpower studies which show a strong relationship between sortie length and failure rate. Figure 6 shows the results of one of these studies. To adjust for Sortie Length a sortie length adjustment factor was generated by dividing the projected sortie length for the A10A by the average sortie length of the comparable systems used in the comparability study. For example: The average sortie for the A-7D derived from DO-56-B-5522 and the Monthly Aerospace Vehicle Status Utilization Report (6-0-338) was 1.66 hours. The projected average sortie length for the A-10A at Davis-Monthan was 2.1 hours. This

B-52D SEA COMBAT MISSION

(9,450 SORTIES 68,217 FH)

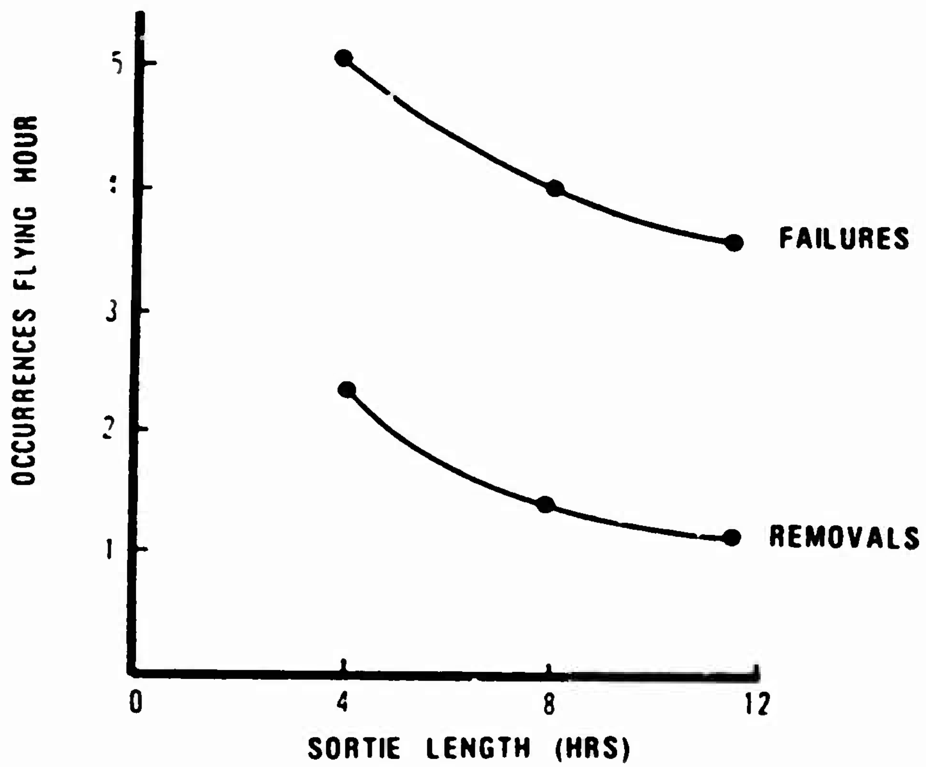


FIGURE 6

value was provided by TAC. The sortie length factor was generated by dividing 2.1 by 1.66 producing a factor of 1.265. Sortie Length adjustment factors were developed for the 16 different systems which were used in the original comparability study. These factors appear in Table 45.

The sortie length factor was applied directly to the original mature MTBF forecast to generate the revised forecast. An example of this is the 44XXX work unit code, the lighting system shown in Table 46. The 44XXX system utilized three different sortie length factors. In 44AXX, Lighting Controls, there was no comparable system; therefore the sortie length factor was subjectively left at 1.0, and the forecast remained the same at 573 hours. In 44BXX, the External Lighting System, the equivalent system was the A-7D with a sortie length factor of 1.265. This raised the forecast from 105 hrs to 133 hrs. In 44CXX, the Interior Lighting System, the comparable system was the F-4E with a sortie length factor of 1.468, thus raising the forecasted MTBF from 64 to 94. These adjustments raised the 44XXX system MTBF from 37 to 50 hours. This method was applied throughout the system for every 3-digit, and when necessary 4-digit, work unit code. The results are displayed in Table 47. The mature forecast rose from 1.5 to 1.78 at the Air Vehicle level.

Application of this sortie length adjustment was not universal. Some systems were discovered, through further research, to have been used in far different ways than the intended use in the A-10A. An example of this is the VHF/AM comm which used very seldom and therefore was not considered representative of the system. Because of this the sortie length factor was left at 1.0.

When the sortie factors were used, they were used in a direct ratio. Although this may not be totally true, it was the only practical means of quantification which could lead to a numerical revision.

2. Revision to Initial Reliability Forecast (MTBF)

Since DT&E data was primarily used for development of the initial reliability forecasts, and the sortie lengths were significantly different between Edwards and Davis-Monthan AFB, a revision to these forecasts was also considered necessary.

A sortie length factor for the inital forecast was generated by dividing the TAC projected operational sortie length of 2.1 hours by the average sortie length during DT&E of 1.53 hours. This produced a sortie length adjustment factor of 1.37. This was directly applied to the original initial forecasts where growth was expected. The mature MTBF's developed in paragraph 1 of this section of the report were used as initial forecasts for those systems where no growth is expected (i.e., WUC's 47, 55, 62, 91, 96, and 97). Reliability growth is further discussed in Part III of the system. A summary of these revised initial forecasts is provided in Table 48.

TABLE 45

SORTIE LENGTH ADJUSTMENT FACTORS

AIRCRAFT	AVG. SORTIE	SORTIE LENGTH ADJUSTMENT FACTOR
F-4E	1.43	1.468
T-37	1.28	1.64
A-7D	1.66	1.265
F-111D	2.81	.747
F-111A	2.34	.9
FB-111A	3.01	.7
T-38	1.22	1.722
F-106	1.8	1.167
OV-10	1.97	1.066
F-105	1.48	1.45
F-15	1.3	1.61
A-37	1.34	1.57
HH-53	2.08	1.00
F-5E	.98	2.14
F-5 A/B	1.23	1.70

TABLE 46

EXAMPLE: SORTIE LENGTH ADJUSTMENT

44XXX - LIGHTING SYSTEM

	COMPARABLE AIRCRAFT	ORIGINAL FORECAST	SORTIE ADJ FACTOR	REVISED FORECAST
44AXX - LIGHTING CONTROLS	N/A	573	1.0	573
44BXX - EXTERIOR LIGHT. SYS.	A-7D	105	1.265	133
44CXX - INTERIOR LIGHT. SYS.	F-4E	64	1.468	94
44XXX - LIGHTING SYSTEM	--	37	--	50

TABLE 47
REVISED MATURE MTBF CALCULATIONS

WUC	COMPARABLE SYSTEM	ORIGINAL MTBF	SORTIE LENGTH ADJ	REVISE MTBF
11A	A-7D	47	1.265	57
11B	A-7D	117	1.265	148
11C	A-7D	75	1.265	95
11D	A-7D	89	1.265	113
11E	A-7D	220	1.265	278
11F	A-7D	134	1.265	170
11	-	15	-	19
12A	N/A**	1000	1.0	1000
12B	N/A**	200	1.0	200
12G	A-7D	147	1.265	186
12K	A-7D	256	1.265	324
12	-	64	-	74
13A	N/A*	31	N/A*	45
13B	N/A*	100	N/A*	142
13C	F-4E	2075	1.486	3083
13D	A-7D	89	1.265	113
13E	A-7D	392	1.265	456
13G	A-7D	1180	1.265	1493
13K	A-7D	1500	1.265	1896
13	-	17	-	24
14A	A-7D	1833	1.265	2319
14C	A-7D	56	1.265	71
14E	A-7D	169	1.265	214
14G	A-7D	950	1.265	1202
14K	A-7D	69	1.265	87
14L	A-7D	31	1.265	39
14N	T-37	218	1.640	358
14	-	13	-	17
23 A-D		38.5	1.00	38.5
23G	A-7D	22	1.265	28
23J	F-111A	225	.90	202.5
23K	F-111A	146	.90	131
23	-	12	-	13.5

* Broken Down to 4-digit level

** Estimate

TABLE 47 (CONT'D)

WUC	COMPARABLE SYSTEM	ORIGINAL MTBF	SORTIE LENGTH ADJ	REVISE MTBF
24A	HH-53	87	1.00	87
24C	A-7D	42	1.265	53
24E	HH-53	included	-	included
24G	HH-53	in 24A	-	in 24A
24	-	28	-	33
41A		included in total		included in total
41B	OV-10	142	1.066	151
41C	OV-10	563	1.066	600
41D	OV-10	6125	1.066	6529
41E	OV-10	907	1.066	967
41F	OV-10	7538	1.066	8036
41	-	98	-	104
42A	A-7D	105	1.265	132
42B	A-7D	773	1.265	978
42C	A-7D	317	1.265	401
42D	A-7D	1246	1.265	1576
42E	A-7D	185	1.265	234
42F	A-7D	186	1.265	235
42G	A-7D	2417	1.265	3057
42	-	39	-	49
44A		573	1.00	573
44B	A-7D	105	1.265	133
44 C-D	F-4E	64	1.468	94
44	-	37	-	50
45A	A-7D	108	1.265	137
45B	A-7D	108	1.265	137
45D*	N/A**	200	1.0	200
45	-	43	-	51

TABLE 47 (CONT'D)

WUC	COMPARABLE SYSTEM	ORIGINAL MTBF	SORTIE LENGTH ADJ	REVISED MTBF
46A	F-5 A/B	320	1.70	544
46B	F-105	628	1.45	910
46C	F-5 A/B	533	1.70	906
46D	A-7D	159	1.265	201
46E	F-5 A/B	207	1.70	352
46F	F-5 A/B	327	1.70	556
46G	F-5 A/B	458	1.70	779
46	-	44	-	67
47A	A-7D	[illegible]1	1.265	115
47	-	91	-	115
49A	F-105	1630	1.45	2363
49B	F-105	165	1.45	239
49	-	150	-	217
51A	A-7D	613	1.265	775
51C	A-7D	67	1.265	85
51E	A-7D	511	1.265	646
51F	F-111A	94	.90	85
51G	A-7D	305	1.265	386
51	-	30.8	-	34.5
52A	F-5E	105	2.14	225
52	-	105	-	225
55A	F-111A	503	.90	453
55B	F-4E	1788	1.468	2625
55	-	383	-	386
62A	A-7D	95	1.265	120
62C	C-5A	168	1.00	168
62	-	61	-	70
63A	F-5E	54	2.14	115
63	-	54	-	115
64A	A-37	147	1.57	231
64	-	147	-	231

TABLE 47 (CONT'D)

WUC	COMPARABLE SYSTEM	ORIGINAL MTBF	SORTIE LENGTH ADJ	REVISED MTBF
65A	F-15	154	1.61	248
65	-	154	-	248
71A	FB-111	122	.70	85.4
71	A-7D	1269	1.265	1605
71	-	111	-	81
72A	F-4E	1100	1.468	1615
72	-	1100	-	1615
74A	A-7D	75	1.265	95
74C	N/A**	50	1.0	50
74E	N/A**	50	1.0	50
74	-	18.8	-	20
75A		119	1.0	119
75B		50	1.0	50
75 C-H	A-7D	49	1.265	62
75	-	20	-	22
76A	F-4E	206	1.486	306
76C	F-4E	1028	1.486	1509
76	-	172	-	254
91A	A-7D	226	1.265	286
91	-	226	-	286
96A	F-105	9896	1.46	14844
96	-	9896	-	14844
97A	A-7D	included	1.265	included
97B	A-7D	in	1.265	in
97C	A-7D		1.265	
97D	A-7D	total	1.265	total
97	A-7D	2239	1.265	2832
A-10A	-	1.5	-	1.78

TABLE 48

REVISED INITIAL MTBF FORECASTS

WUC	ORIGINAL INITIAL FORECAST	REVISED INITIAL FORECAST
11XXX	7.0	9.6
12XXX	25.0	36.5
13XXX	6.5	9.0
14XXX	10.5	14.4
23XXX	5.4	7.5
24XXX	28	33
41XXX	40	54
42XXX	25	34
44XXX	13	18
45XXX	15	20.5
46XXX	29	40
47XXX	91	115
49XXX	58	79.6
51XXX	22	30
52XXX	144	144
55XXX	393	386
62XXX	61	70
63XXX	147	201
65XXX	146	200
71XXX	54.6	75
72XXX	875	1188
74XXX	15	20
75XXX	10.3	14
76XXX	172	254
91XXX	226	286
96XXX	9896	14844
97XXX	2239	2832
TOTAL	.85	1.1

PART II - MAINTENANCE (MMH/FH) REVISIONS

1. Revision to Mature Maintenance (MMH/FH) Forecast

A. Support General

The maintenance data from both the DT&E and operational environments indicate that the actual support general MMH/FH measured was very close to the mature forecast. Based on these observations, the support general mature MMH/FH was only revised to take into account the change in anticipated sortie length from 2.0 hour sorties to 2.1 hour sorties. This adjustment for sortie length was accomplished in the same manner as the MTBF revisions. Results of the revision are shown in Table 49.

In addition to the sortie length adjustment, TAC requested that munitions handling be included in the revised forecast. A forecast for this type of maintenance was purposely excluded in the original forecast. The following parameters were used for munitions maintenance forecasting:

Crew Size: 4

Frequency: .36 MA/FH (75% of sorties are weapons/gun sorties)

Task time: 1.0 MH/MA (.5 hr upload - .5 hr download)

4 mean X .36 MA/FH X 1.0 MH/MA - 1.44 MMH/FH

B. Non-Support General

In revising the mature Non-Support General MMH/FH forecast two areas of concern which required revision were the original estimates of subystem task times and the revision of mature MTBF values.

TABLE 49

REVISED SUPPORT GENERAL MMH/FH FORECASTS

WUC (WORK UNIT CODE)	REVISED FORECAST
01 - GROUND HANDLING*	3.3
02 - AIRCRAFT CLEANING	1.1
03 - SCHEDULED INSPECTION	3.5
04 - SPECIAL INSPECTION	1.4
05 - PRESERVATION	.1
06 - ARM/DE-ARM	.5
07 - RECORDS DOCUMENTATION	.1
09 - SHOP SUPPORT GENERAL	.7
TOTAL	10.7

* Munitions handling is included in this forecast.

As data from DT&E and the 355 TFW was reviewed it became evident that several of the original estimates of subsystem task times were much too conservative. It was therefore necessary to revise several of these task time estimates. TAC and AFTEC (Air Force Test and Evaluation Center) were also in the process of revising several of the subsystem estimates. However, data from this 'official' task time study was not available at the time the revised forecasts were required. Seven subsystems task time estimates were revised. These revisions were subjectively developed. Table 50 is a comparison of the original task time estimate, the Davis-Monthan Apr - Sep 76 actuals and the revised forecasts.

The change in forecasted mature MTBF's also necessitated a change in the Non-Support General mature MMH/FH forecast. Table 51 shows the recalculation of the Non-Support General mature forecast. The remaining areas of manhour expenditure within the Non-Support General category were not changed. Table 52 is a summary of the entire revised Non-Support General mature forecast.

C. Other Maintenance

TCTO maintenance for the mature aircraft was not revised. Consequently, the 1.0 MMH/FH originally estimated was retained.

2. Revision to Initial Maintenance (MMH/FH) Forecasts

A. Support General

A review of the learning factors applied during the original forecast indicates that no learning was experienced at Davis-Monthan AFB.

TABLE 50

TASK TIMES - ACTUAL VS. FORECASTED

WUC	L - COMM PREDICTION	ACTUALS APR - SEP	REVISED ESTIMATE
11	3.2	1.8	1.8*
12	5.3	5.9	5.3
13	7.5	4.3	4.3*
14	9.5	7.9	7.9*
23	15.2	5.3	15.2
24	6.2	3.9	3.9*
41	8.9	6.5	8.9
42	7,9	4.6	4.6*
44	3.1	2.1	3.1
45	8.1	6.1	6.1*
46	13.0	29.8	13.0
47	6.0	5.5	6.0
49	11.1	13.0	11.1
51	9.9	5.2	5.2*
52	5.3	21.7	5.3
55	6.0	1.3	6.0
62	4.6	4.2	4.6
63	3.9	9.6	3.9
64	4.5	9.0	4.5
65	6.8	12.3	6.8
71	5.2	6.3	5.2
72	8.2	-	8.2
74	6.4	10.3	6.4
75	10.3	9.4	10.3
76	8.4	11.7	8.4

* Subsystems that were revised due to actual data.

TABLE 51

REVISED MATURE NON-SUPPORT GENERAL MMH/FH CALCULATIONS

(ON & OFF A/C ONLY)

WUC	MATURE MTBF	TYPE 2 / TYPE 1 RATIO	FREQUENCY MA/FH	MH/MA	ON AIRCRAFT MH/FH APR-SEP	OFF A/C / ON A/C RATIO	OFF AIRCRAFT MH/FH	TOTAL MH/FH
11	19	3.0	.158	1.8	.284	.15	.043	.33
12	74	2.0	.027	5.3	.143	.15	.021	.16
13	24	1.4	.058	4.3	.250	.5	.125	.38
14	17	1.4	.082	7.9	.648	.15	.097	.75
23	13.5	1.3	.096	15.2	1.463	.3E	.439	1.90
24	33	1.2	.036	3.9	.140	.2	.028	.17
41	54	1.4	.025	8.9	.226	.1	.022	.25
42	49	1.4	.029	4.6	.133	.5	.067	.2
44	50	1.25	.025	3.1	.078	.15	.012	.09
45	51	1.3	.026	6.1	.58	.15	.024	.18
46	67	1.4	.021	13.0	.273	.15	.041	.31
47	115	1.3	.011	6.0	.066	.15	.010	.08
49	217	1.4	.006	11.1	.067	.2	.013	.08
51	35	1.2	.034	5.2	.177	.2E	.035	.21
52	225	1.1	.005	5.3	.027	.5	.013	.04
55	386	1.2	.003	6.0	.018	.05	.001	.02
62	70	1.1	.016	4.6	.074	1.5	.111	.19
63	115	1.1	.009	3.9	.035	1.5	.053	.09
64	231	1.2	.005	4.5	.023	.5	.011	.03
65	248	1.1	.004	6.8	.027	1.0	.027	.05
71	81	1.1	.014	5.2	.073	1.7	.124	.20
72	1615	1.1	.001	8.2	.008	1.4	.011	.02
74	20	1.06	.053	6.4	.339	1.4E	.475	.81
75	22	1.5	.068	10.3	.700	1.0E	.700	1.40
76	254	1.3	.005	8.4	.042	.4	.017	.06
91	296	-	-		-	-	-	.10
96	14844	-	-		-	-	-	.01
97	2832	-	-		-	-	-	.04
					5.70		2.459	8.15

TABLE 52

SUMMARY REVISED NON-SUPPORT GENERAL MMH/FH FORECAST

ON-AIRCRAFT	5.7
OFF-AIRCRAFT	2.5
SPECIAL GUN INSPECTIONS	.1
SPECIAL BATTERY INSPECTIONS	.2
COMPONENT TIME CHANGES	.1
CANNIBALIZATION	.2
	8.8

This should have been expected since a majority of the D-M maintenance personnel were the same people who maintained the aircraft during the DT&E program at Edwards. It was therefore decided to eliminate learning from the support general initial forecast. Consequently, the initial forecast is identical to the mature forecast -10.7 MMH/FH.

B. Non-Support General

Since the on and off aircraft maintenance portions of non-support general MMH/FH are directly related to the MTBF forecasts, the mature forecasts must be adjusted to account for the difference between initial MTBF and mature MTBF. Table 53 is a recalculation of the on and off aircraft portions of non-support general MMH/FH using the revised initial MTBF forecasts. Cannibalization maintenance was also increased based on the difference in reliability.

In addition to revision required for reliability purposes, it was also decided to eliminate learning from the on and off aircraft portions of non-support general for the same reaon it was removed from support general. The learning factors initially used were based on several assumptions. Two assumptions which proved to be in error were that the newer maintenance personnel did not have the learning problem anticipated and the F-15 initial site activation experience was not representative of the A-10 experience. Therefore, the only difference between the revised mature Non-Support General MMH/FH and the revised initial Non-Support General MMH/FH is the difference between initial and mature reliabilities. Table 54 is a summary of the revised initial Non-Support General MMH/FH.

TABLE 53

REVISED INITIAL NON-SUPPORT GENERAL MMH/FH CALCULATIONS

(ON & OFF A/C ONLY)

WUC	INITIAL MTBF	TYPE 2 / TYPE 1 RATIO	FREQUENCY MH/FH	TASK TIME MH/MA	ON-ACFT MH/FH	OFF A/C / ON A/C RATIO	OFF-ACFT MH/FH	TOTAL MH/FH
11	9.6	3.0	.312	1.8	.562	.15	.084	.646
12	37	2.0	.054	5.3	.286	.15	.043	.329
13	9.0	1.4	.156	4.3	.669	.5	.334	1.003
14	14.4	1.4	.097	7.9	.768	.15	.115	.883
23	7.5	1.3	.173	15.2	2.635	.3E	.790	3.425
24	33	1.2	.036	3.9	.42	.2	.028	.170
41	54	1.4	.026	8.9	.231	.1	.023	.254
42	34	1.4	.041	4.6	.89	.5	.095	.284
44	18	1.25	.069	3.1	.215	.15	.032	.248
45	20.5	1.3	.063	6.1	.387	.15	.058	.445
46	40	1.4	.035	13.0	.455	.15	.068	.523
47	115	1.3	.011	6.0	.068	.15	.010	.078
49	80	1.4	.018	11.1	.194	.2	.039	.233
51	30	1.2	.040	5.2	.208	.2E	.042	.250
52	144	1.1	.008	5.3	.040	.5	.020	.060
55	386	1.2	.003	6.0	.019	.05	.001	.020
62	70	1.1	.016	4.6	.072	1.5	.108	.181
63	63	1.1	.017	3.9	.068	1.5	.102	.170
64	201	1.2	.006	4.5	.027	.5	.013	.040
65	200	1.1	.006	6.8	.037	1.0	.037	.075
71	75	1.1	.015	5.2	.076	1.7	.130	.206
72	1188	1.1	.001	8.2	.008	1.4	.011	.018
74	20	1.06	.053	6.4	.339	1.4E	.475	.814
75	14	1.5	.107	10.3	1.104	1.0E	1.104	2.207
76	254	1.3	.005	8.4	.043	.4	.017	.060
91	286	-	-	-	-		-	-
96	14844	-	-	-	-		-	-
97	2832	-	-	-	-		-	-
TOTAL					8.843		3.779	12.622

TABLE 54

SUMMARY REVISED INITIAL NON-SUPPORT GENERAL MMH/FH

o ON AIRCRAFT	9.6
o OFF AIRCRAFT	5.0
o SPECIAL GUN INSPECTIONS	.1
o SPECIAL BATTERY INSPECTIONS	.2
o COMPONENT TIME CHANGES	.1
o CANNIBALIZATION	.6
	15.6

C. Other Maintenance

Based on actual A-10 experience at Davis-Monthan, an initial forecast of 4.0 MMH/FH was developed for TCTO maintenance. It was also anticipated that this level of effort for TCTO's will remain constant for about one year and then significantly drop to the mature value.

Table 55 is a summary of the revised total MMH/FH forecast for the entire A-10 aircraft.

TABLE 55

SUMMARY REVISED TOTAL MMH/FH FORECAST

	MATURE	INITIAL
SUPPORT GENERAL	10.7	10.7
NON-SUPPORT GENERAL	8.8	12.6
OTHER	1.0	4.0
TOTAL	20.5	27.3

TABLE 56

SUMMARY OPERATIONAL MTBF NORM DATA

AIRCRAFT	MTBF	UTILIZED RATE	NORM - G UNS	NORM - G SCH	FLYABLE
A-7	1.2	23	16.7	5.5	12.4
A-37	2.1	24	11.6	6.5	1.0
RF-4C	.89	23	19.8	5.7	2.9
F-4C	.63	21	25.0	5.1	7.5
F-4E	.83	23	18.6	6.6	9.7
F-15	.71	-	29.9	15.6	1.8
O-2	2.4	24	8.7	6.6	2.3
OV-10	1.8	30	11.3	5.5	2.5
T-37	3.3	38	9.2	7.2	2.6
T-38	2.4	37	11.6	8.7	3.8
F-111D	.45	18	43	4.0	8.9
F-111F	.98	26	18.2	6.3	.7

SOURCE:

(1) D056

(2) HAF-LGM (AR) 7107 (FEB - JUL 75)

PART III - RELIABILITY GROWTH

Until now, it has not been discussed how the aircraft or subsystem would achieve their mature reliability. The purpose of this part of the report is to briefly discuss the reliability growth concept used.

In reference (1), J. T. Duane observed that the logarithm of cumulative MTBF was a linear function of the logarithm of time. This theory is extremely popular for modeling reliability growth. The Duane model was chosen because of its simplicity and because it has been somewhat validated for a complex system since its derivation in 1964 (Reference 3). Graphically, this theory can be represented by a straight line on log-log graph paper.

Curves were generated by plotting the initial MTBF (or MMH/FH) forecasts at 450 flying hours and the mature forecast at 71,000 flying hours. The points were then connected with a straight line. The slope of this line represents the forecasted rate of reliability growth. This is consistent with the Duane theory of growth. An equation can then be formed to analytically relate MTBF to flying hours. That is,

$$MTBF_{i} = (MTBF)_{MATURE} \left(\frac{FHi}{71,000} \right)$$

where α = the slope of the line. An example of this is the 11XXX WUC subsystem - Airframe. The initial MTBF at 450 flying hours was 9.6 hours and the mature MTBF at 71,000 flying hours was 19 hours. These points were connected by a straight line with a slope of .13488. This makes the equation for reliability growth;

$$MTBF_i = 19 \left(\frac{FH_i}{71{,}000}\right)^{.13488}$$

Therefore, for any point in time prior to the accumulation of 71,000 fleet flying hours, MTBF's may be forecasted. MMH/FH curves were generated in a similar manner. These curves were developed at the 2 and 3 digit WUC level for MTBF's and the 2 digit level only for MMH/FH. Figures 7 and 8 show the air vehicle growth curves from R&M.

In order to place bounds on these growth curves, 90% confidence intervals were generated using the standard deviation from the operational data and the student's t distribution factors. The equation for 2-sided confidence intervals using student's t is:

$$X \pm \frac{t_{\alpha/2,\ N-1}\ \bar{S}}{N}$$

where $t_{\alpha/2,\ N-1}$ is the value of student's t for a confidence of and a sample size of N. $\bar{S}$ is the statistical standard deviation corrected for sample size. Sample size was based on months, i.e., each month is one sample. Six months of operational data (April - September 1976) provided the standard deviation and the first sample size. In order to extrapolate the confidence intervals other sample sizes were generated using the flying hours at certain calendar times. These were 5000 flying hours at 15 months and 41 months at 71,000 flying hours. Thus, the points used for calculating and plotting the confidence intervals are as follows:

6 samples at 1135 hours

15 samples at 5000 hours

41 samples at 71000 hours

The value for student's t was based on these sample sizes and are as follows:

6 samples - 2.015

15 samples - 1.761

41 samples - 1.684

As an example the 11XXX system MTBF curve is shown in Figure 7. The standard deviation was 15.14 so the confidence intervals were constructed around the points

1135 hours - $\pm$ 12.45

5000 hours - $\pm$ 6.88

71000 hours - $\pm$ 3.98

Confidence intervals were generated for MTBF and MMH/FH at the 2-digit Work Unit Code level only and for the Air Vehicle forecast.

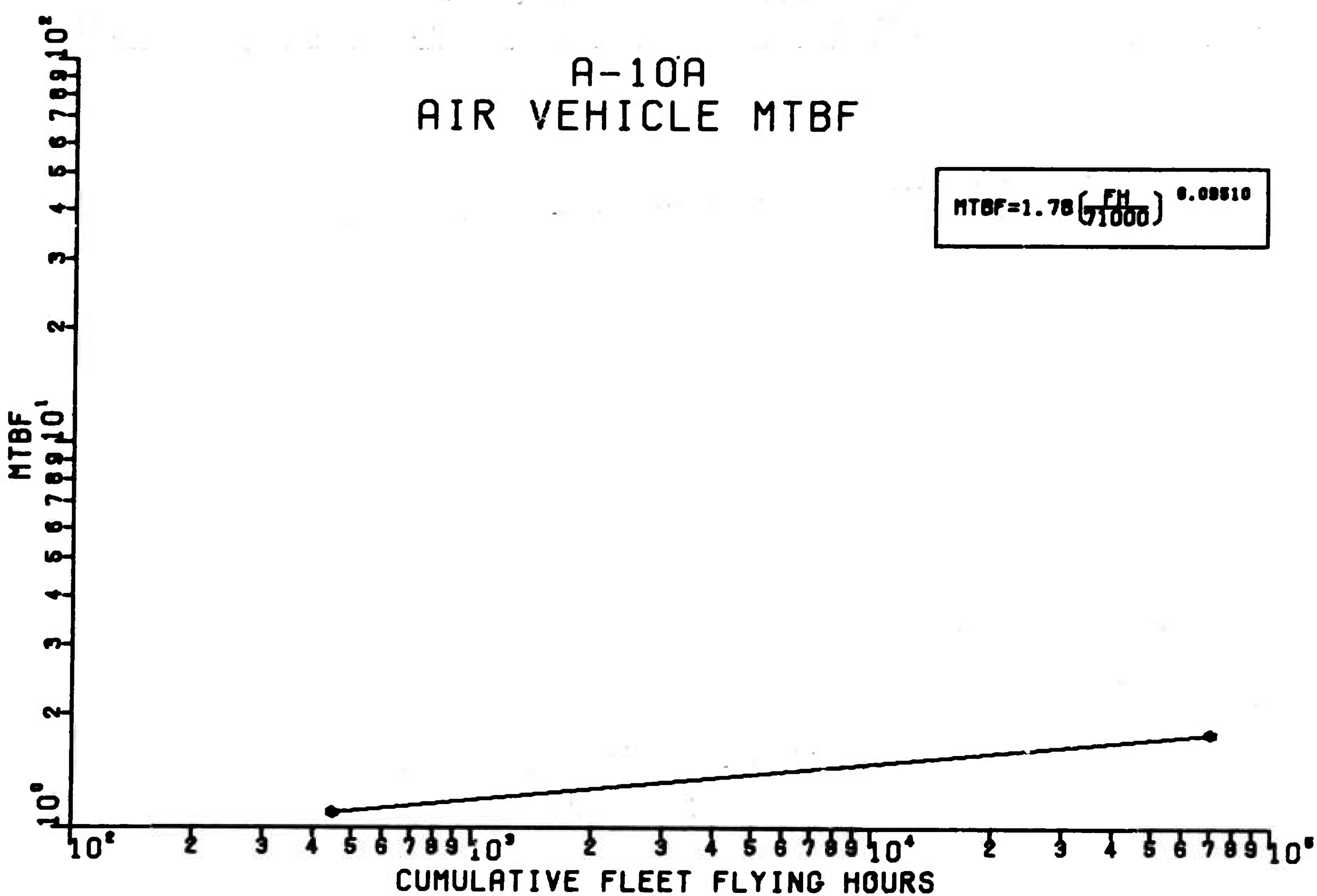

A-10A
AIR VEHICLE MTBF
MTBF=1.78(FH/71000) 0.08810
MTBF
CUMULATIVE FLEET FLYING HOURS

FIGURE 7

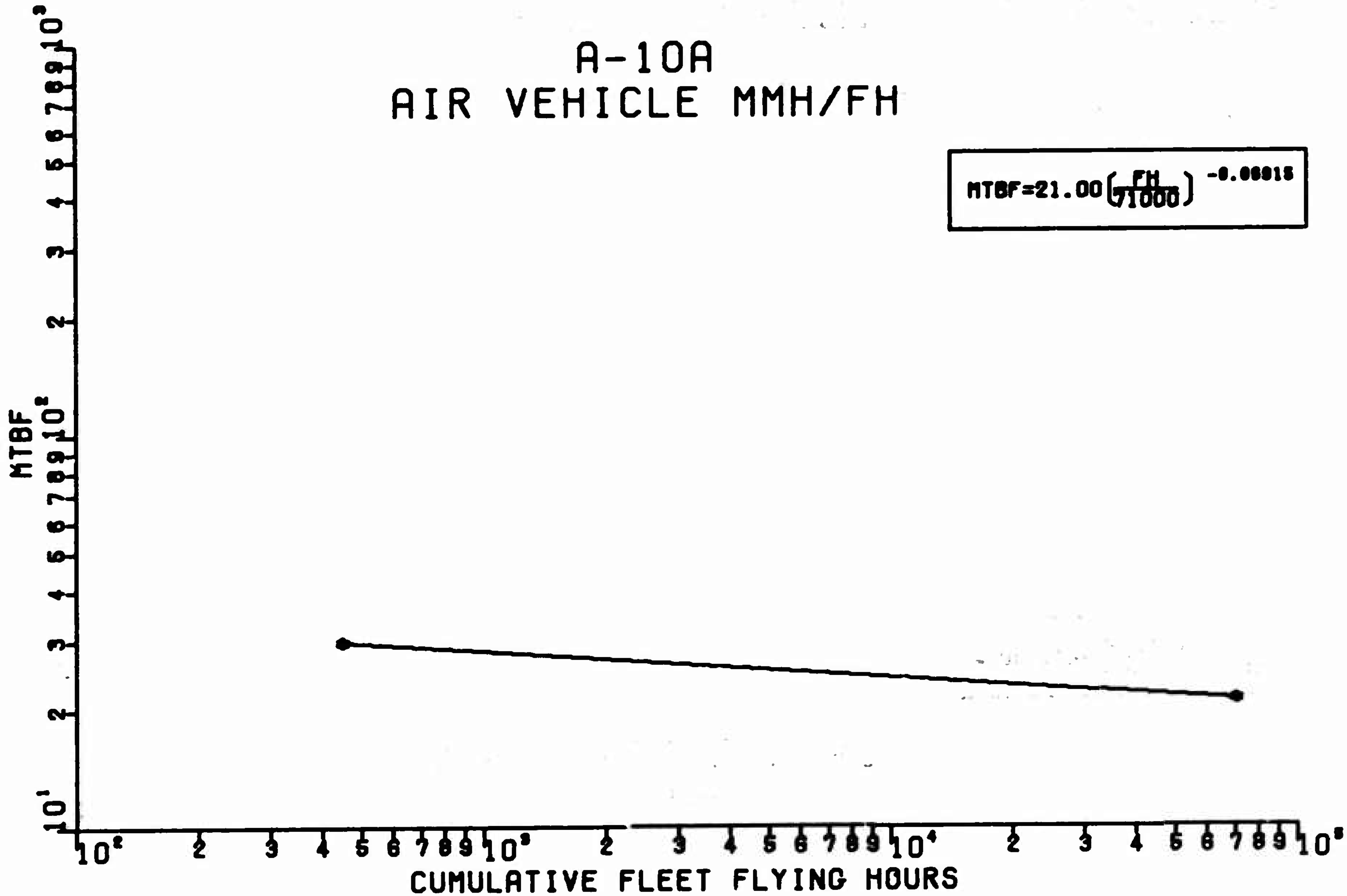

A-10A
AIR VEHICLE MMH/FH
MTBF=21.00(FH/71000)
MTBF
CUMULATIVE FLEET FLYING HOURS

FIGURE 8

SECTION V

CONCLUSIONS AND RECOMMENDATIONS

1. CONCLUSIONS

As stated earlier, the purpose of this report was to provide a usable technique for forecasting operational MTBF and MMH/FH. Throughout the development of this technique, great emphasis was placed on deriving general methods that could be used by other developmental organizations. Given the prerequisite data that was used for these A-10 forecasts, similar calculations can, and should be accomplished on other systems. Although this type of generalized approach may lack some specific detailed information, at the component level, it can be used to identify where additional emphasis is necessary. It also provides a useful tool in the comparison of other types of weapons systems under development at the same time. This type of visibility does not presently exist within the Air Force.

2. RECOMMENDATIONS

The following recommendations are considered essential within the framework of the objective of this report:

A. Throughout the next year, actual A-10A experience should be used to validate the general approach taken. Differences between forecasted values and actual should be evaluated to determine if the technique requires further revision.

B. The reasons for significant differences between actual and forecasted should be fed back to the personnel performing the original comparability analysis, deriving reliability complexity factors and estimating the task times. This effort would assure a closed loop to preclude inaccuracies in future programs.

C. All major projects/programs with available prerequisite data should be required to use this methodology (or something similar) to provide operational R&D measures of merit.

APPENDIX A

MTBF/NORM CORRELATION STUDY

As part of the MTBF and MMH/FH forecasting, a request was made to assist in the identification of any correlation between MTBF and NORM (Not-Operationally-Ready-Maintenance). NORM is subdivided into two categories NORM-G (Grounded) and NORM-F (Flyable). These terms indicate the severity of the maintenance task required to be accomplished versus its effect on the aircraft mission. An event which is categorized as NORM-G must be accomplished before the aircraft can fly whereas an event categorized as NORM-F may be delayed until the mission is complete. Within the NORM-G category there exists two additional classifications; NORM-G (Unscheduled) and NORM-G (Scheduled). NORM-G (Uns.) is that maintenance which results from failure of mission essential equipment. NORM-G (Sch.) is the type of maintenance associated with phased inspections and TCTO maintenance.

Since NORM-G is divided into scheduled and unscheduled categories and is reported in those categories within the Air Force Data System, it was decided to structure a mathematical relationship based on these categories. NORM-G (Uns) was chosen as the most logical point of departure for determining a MTBF/NORM relationship since unscheduled maintenance is directly a result of hardware failures. Information on TAC maintained aircraft was obtained from both the D056 "product performance" data system and from the HAF-LGM(AR)7107 report.

Table 56 is a summary of the data used in the analysis. Using this data Figure 9 was drawn and a mathematical equation (best-fit) developed;

$$\text{NORM-G(UNS)} = 2.5 + \frac{16.7}{\text{MTBF}}$$

This expression provides the user with a tool of forecasting NORM-G(UNS) when an aircraft MTBF is known. NORM-G(SCH), as can be seen from Table 57 is a very stable value from aircraft to aircraft with a few exceptions. This is probably a result of most aircraft having similar phased inspection requirements. Therefore, an average value was chosen as a forecast of NORM-G(SCH) for the A-10. The combined NORM-G forecast for the mature A-10A aircraft was

$$\text{NORM-G} = \text{NORM-G(UNS)} + \text{NORM-G(SCH)} = 2.5 + 16.7/\text{MTBF} + 6.0$$

$$\text{NORM-G} = 2.5 + 16.7/1.78 + 6.0$$

$$\text{NORM-G} \quad 18$$

It is felt that this estimate is realistic. However, future analyses should be performed to further validate the approach developed.

AIRCRAFT NORM-G (Scheduled Maintenance)

AIRCRAFT	NORM-G (SCH)
F-4C	5.1
RF-4C	5.7
F-4E	6.6
O-2A	2.2
A-37B	6.5
A-7D	5.5
F-111D	4.0
F-111F	6.3
T-37B	7.2
T-38A	8.7
OV-10A	5.5

TABLE 56

NORM/MTBF CORRELATION

$$\text{NORM-G (UNS)} = 2.5 \frac{16.7}{\text{MTBF}}$$

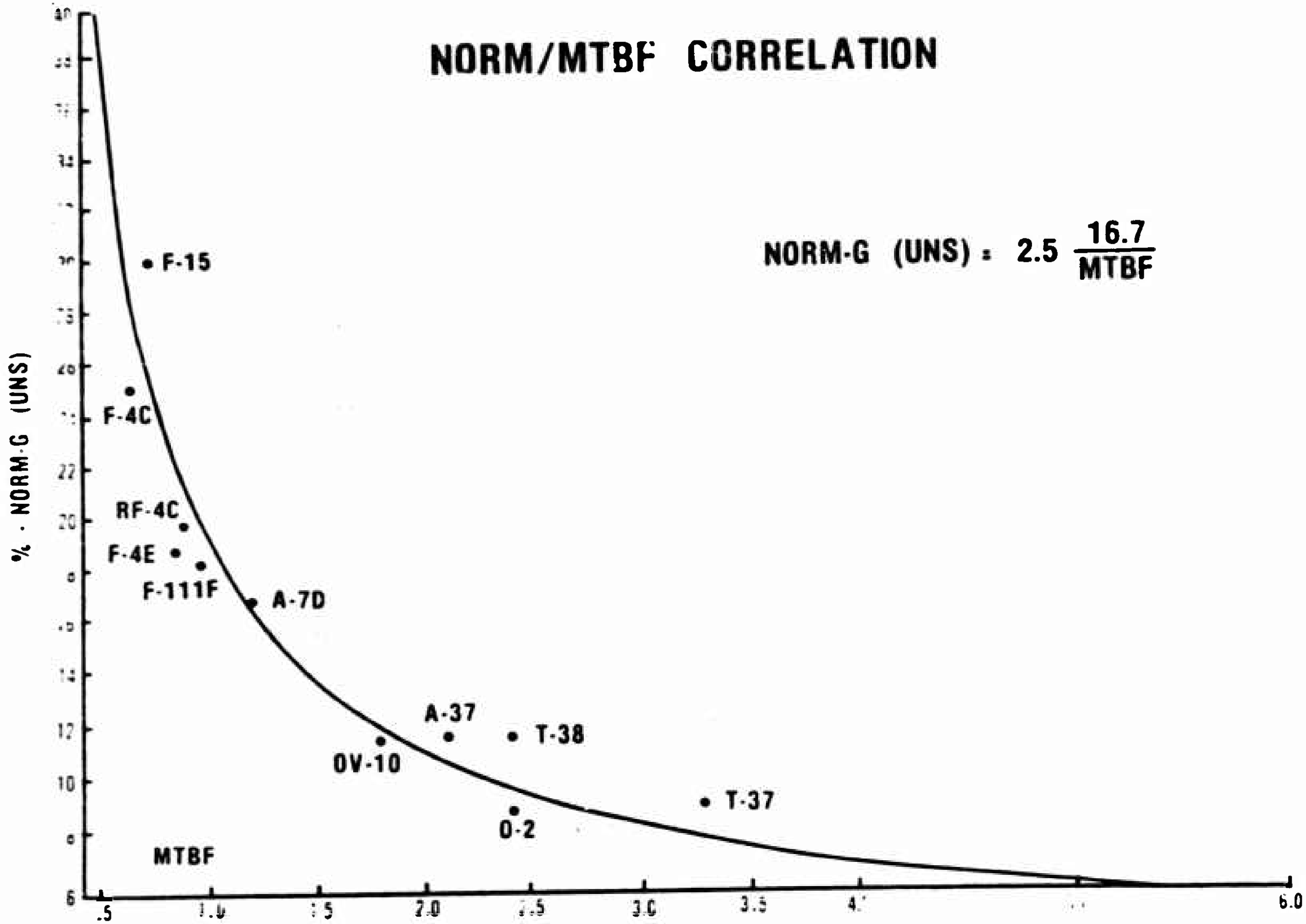


FIGURE 9

REFERENCES

1. DUANE, J.T., "Learning Curve Approach to Reliability Monitoring," IEEE Transactions, Aerospace, Vol 2, 1964.

2. RADC-TR-75-253, Reliability Growth Study, October 1975, p. 18.

3. ASD-TR-73-22, Research Study of Radar Reliability and Its Impact on Life Cycle Costs for the APQ-113, -114, -120 and -120 and -144 Radars, April 1973.

*U.S.Government Printing Office: 1977 — 757-001/55